COMMONWEALTH OF KENTUCKY
BEFORE THE KENTUCKY STATE BOARD
ON ELECTRIC GENERATION AND TRANSMISSION SITING

In the Matter of the Application of Glover Creek Solar, LLC, for a Construction Certificate to Construct a Merchant Electric Generating Facility	)))	**Case No. 2020-00043**

RESPONSES TO SITING BOARD STAFF'S
FIRST REQUEST FOR INFORMATION ON REHEARING

Glover Creek Solar, LLC ("Glover Creek"), by counsel, respectfully submits the following responses to the Siting Board Staff's First Request for Information on Rehearing.

Glover Creek is very grateful to the Siting Board for the opportunity to respond to their request for information about Glover Creek's Petition for Reconsideration and Clarification. We appreciate the opportunity to provide information about the solar industry and projects of the scope and scale of Glover Creek, which we know are something new in Kentucky. We also appreciate the time it requires for staff and Siting Board to consider these issues and learn about this new technology.

Glover Creek recognizes that while some of the information we include herein is common knowledge in the solar industry, it is not common knowledge in the general public. We appreciate the opportunity to enter this information into the record, and to hopefully help increase the knowledge and understanding of our industry in Kentucky.

We have been impressed with the level of interest and engagement about solar that we have received in the communities where we are working in Kentucky, and especially in the demand for solar energy by some of Kentucky's largest employers. We hope that solar will become a new piece of Kentucky's diverse energy future, bringing new economic development to the communities where our projects are located.

Glover Creek hopes the information we have provided herein is helpful, and are available to discuss this further and hopefully address any remaining Siting Board questions or information needs at the Siting Board's discretion.

Respectfully submitted,

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ATTORNEYS FOR GLOVER CREEK SOLAR, LLC

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CERTIFICATION OF RESPONSES TO INFORMATION REQUESTS

This is to certify that I have supervised the preparation of Glover Creek Solar, LLC's responses to the Siting Board Staff's First Request for Information of Rehearing and that the responses are true and accurate to the best of my knowledge, information, and belief after reasonable inquiry.

Date: January 19, 2021

[signature]
Carson Harkradar

1. Refer to Glover Creek's Petition for Reconsideration and Clarification (Petition) at pages 2–3 regarding the need to minimize conditions and uncertainty in order to obtain a comprehensive construction bid package. Explain in more detail and with supporting information how the mitigation measures identified in the Petition would create barriers for merchant solar development in Kentucky, including the Glover Creek solar project.

Response: In Glover Creek's Petition, the references to ambiguity and uncertainty referred specifically to the following Siting Board conditions, which would create barriers for merchant solar development in Kentucky due to lack of clarity or specificity:

<u>Conditions 2 and 4</u>

Regarding conditions #2 and 4, there is uncertainty around what types of changes the Siting Board will consider "material" in the site development plan.

Glover Creek's future decisions regarding the suppliers of the solar panels, racking systems, inverters, and other equipment will create changes to the locations of the equipment within the solar project footprint, compared with the site development plan presented in the Siting Board application, because different racking systems and inverters require different layout configurations and these sourcing decisions are made closer to the time of construction. The subjective nature of the adjective "material" in the Siting Board permit condition raises questions as to whether any change in the layout would be considered material. For example, Glover Creek would not consider a change in specific location of an inverter or solar panel to be a material change so long as the change does not exceed thresholds set by the Siting Board, but it is currently unclear whether the Siting Board shares that view. In its Petition, Glover Creek identified six actions that it considers to be a material change that could create a negative impact to the Project's surroundings:

- An increase in the footprint;
- A decrease in setback distances;
- A change in location of vegetative buffers;
- Increased noise levels above what was proposed in this matter or reduced buffering, such that there is material difference in noise at the property boundary;
- Increase in height of infrastructure that would be noticeable from neighboring properties; and
- Alteration in the type of equipment used at the facility that would create additional noise or other negative impact to surrounding properties.

If the Siting Board agrees to modify conditions #2 and 4 as proposed by Glover Creek in the Petition and clarify that these six conditions are the conditions that would be considered material, this would provide Glover Creek with more certainty.

Currently, uncertainty about what changes will be considered material by the Siting Board will add weeks or months of delay, and cost, to the project design and procurement process. Under Glover Creek's current Siting Board permit, once final solar panel, racking, inverter, and other equipment decisions are made and the site layout plan finalized accordingly, Glover Creek will need to submit a revised layout to the Siting Board with enough time for the

Siting Board to review the new layout, request additional information, and render a decision on whether any of the changes are considered "material". This process could be expected to last at least one month, and likely longer if the Siting Board has questions about the new layout and configurations, or considers some changes "material," requiring Glover Creek to change the final layout. During this period of time, Glover Creek will not be able to confirm sourcing plans and procure equipment. These delays may impact Glover Creek's ability to secure financing in a timely manner, because financing is usually not finalized until permitting and sourcing decisions are completed, and, because of the current uncertainty in what changes would be considered material, the Siting Board permit may not be considered complete until the final site plan is approved by the Siting Board. These delays and uncertainty create barriers for solar energy because they will delay critical sourcing decisions and development steps and consume company resources without, in Glover Creek's opinion, providing benefit to the Siting Board or Summer Shade community. Glover Creek submits that by clarifying the site plan changes that would be considered "material" to the list of six changes recommended by Glover Creek, the Siting Board will provide the project's neighbors with protection against any changes which would materially impact their experience of the project, and also provide Glover Creek with certainty that will greatly facilitate the sourcing and financing process.

Glover Creek notes that it is typical in a planning and zoning process to provide a final site plan for staff review, and Glover Creek is not opposed to doing so. Our concern is that the criteria for the final Siting Board review is vague on what site layout changes will be considered "material." Glover Creek respectfully requests clarification which will reduce risk, delays and uncertainty for the project during the final site design, procurement, and financing process.

Condition 7

Condition #7 requires Glover Creek to install a vegetative buffer "where there are potential visual or noise impacts created by the solar facility." The word "impacts" in the condition is vague because it does not clarify what impacts are necessary to consider. If a section of the solar project sits next to an agricultural field, is a view of the solar facility from that agricultural area considered an "impact"? In order to meet a conservative interpretation of this condition, Glover Creek may elect to install a vegetative buffer around additional areas of the project site, which would increase costs. However, a site plan with proposed vegetative buffer locations was presented at public meetings, and no neighbors or community members asked for modifications. The ambiguity in the language of the condition means that Glover Creek must choose whether to take on risk by installing a buffer in accordance with the site plan, incur additional cost by installing additional buffer compared to what was shown to the community, or submit a request to the Siting Board for clarification, which we have done in the Petition. The ambiguity in the language in the condition creates a barrier because it does not provide Glover Creek with clear direction as to where to plant the vegetative buffer in order to comply with the Siting Board permit.

Additionally, the requirement for additional temporary measures in the buffer does not clarify what type of temporary measures would be considered sufficient to meet the requirement for "additional temporary buffers." Glover Creek has therefore sought clarification as to what the Siting Board considers an appropriate additional temporary buffer.

Because no members of the community opposed Glover Creek's application or voiced concerns about the vegetative buffer, following substantial community consultation and opportunity for review and comment as described in Glover Creek's original application, Glover Creek submits that the vegetative buffers proposed in the application should satisfy the Siting Board's concern that the proposed vegetative buffer will provide the community with reasonable protection.

<u>Condition 8</u>

Condition #8 also includes language that does not provide Glover Creek with clear direction on where the vegetative buffer should be planted in order to comply with the condition. The ambiguity in the language in the condition creates a barrier because it does not provide Glover Creek with clear direction as to where to plant the vegetative buffer in order to comply with the permit.

<u>Condition 17</u>

Condition #17 includes language that does not provide Glover Creek with clear direction on how to comply with the condition, and who will be responsible for verifying compliance. The condition requires Glover Creek to "fix or pay for damage from Class 21 vehicle trips to the Project site." This is a straightforward requirement, but compliance with the requirement is not necessarily straightforward. It is important for Glover Creek to provide clear and detailed direction to its transportation subcontractors regarding exactly how they should provide services, and what the transportation subcontractors should do to show Glover Creek that they have complied with Glover Creek's permit. Because the language in the Siting Board permit condition is not specific as to how to confirm compliance, Glover Creek will need to create a compliance plan for its subcontractor, which may or may not match what the Siting Board considers adequate. This uncertainty creates risk, which Glover Creek will need to carry, or which Glover Creek will pass onto its subcontractor. If risk is passed to the subcontractor, the subcontractor will price that risk accordingly. This is an example of how conditions that are not specific can add cost and risk to the project.

For example, disputes may arise if neighbors or local officials deem Glover Creek to be out of compliance with the condition, but there is not a clear and agreed mechanism for Glover Creek and its contractor to use to confirm whether it has complied. Glover Creek's intention in seeking clarification to this condition is to set out a clearly defined process for compliance which is more detailed and specific than the language in the original Siting Board condition.

Witness: Carson Harkrader

2. Refer to the Petition at page 6.

a. Explain whether Glover Creek received any comments or any other public response regarding the size of the vegetative buffer to reduce noise levels.

Response: Glover Creek did not receive any comments or any other public response regarding the size of the vegetative buffer to reduce noise levels. Glover Creek did not receive comments or any other public response regarding noise levels in general.

In the experience of Glover Creek and its affiliates, vegetative buffers are typically planted around solar facilities to reduce the visual impact of solar projects, but not to mitigate noise concerns. Carolina Solar Energy, the parent company of Glover Creek Solar, LLC, was the developer of 45 operating solar projects with setback distances similar to Glover Creek, and is not aware of any complaints raised because of operation noise from an existing solar project.

b. Explain whether the Glover Creek developers have ever been required to plant vegetative buffers taller than three feet at the outset of a solar project to reduce visual and noise impacts.

Response: Yes, Carolina Solar Energy has experience developing solar projects in counties that have solar ordinances that require vegetative buffers to be planted that are taller than three feet at the time of planting. The maximum height that we have seen required at the time of planting, to the knowledge of our current staff, is 6 feet.

c. Provide an explanation as to what would be considered an industry best practice as it relates to planting vegetative buffers to mitigate against noise and visual

issues.

Response: Carolina Solar Energy's experience is in North Carolina and Virginia. In our experience, there is no "typical" or "best practice" buffer, as buffer requirements vary widely from county to county. If a buffer is required, the most common design requirement we have seen is a single row or double row of evergreen shrubs (Glover Creek has proposed a staggered double row). In counties in North Carolina that do not have planning and zoning, like Metcalfe County, projects are often built with no vegetative buffer.

Example images of projects with a vegetative buffer consisting of a staggered double row of evergreen shrubs, and from projects with no vegetative buffer, are attached as Exhibit 1.

In our experience, neither planning and zoning departments nor neighbors are typically concerned about noise impacts from solar projects, either from construction or operation, and do not intend or expect the vegetative buffers to mitigate against noise generated by the projects. Please refer to a letter from GAI Consultants, attached as Exhibit 2 for more detailed information regarding vegetative buffers and noise. GAI's conclusion is that vegetative buffers of the size and scope proposed at Glover Creek have no discernable noise reduction impact.

Importantly, operational noise is not expected to have an effect on the surrounding properties. A field study of two utility scale solar projects prepared for the Massachusetts Clean Energy Center concluded that "[a]ny sound from the PV array and equipment was inaudible at set back distances of 50 to 150 feet from the boundary." The study is attached as Exhibit 3.

d. Explain whether Glover Creek will use a competitive bid process or some other process to procure the plants used in the vegetative buffer.

Response: The plants used in the vegetative buffer are typically procured by the general construction contractor via sub-contract, which is typically bid competitively to landscaping companies that serve the local area.

e. Provide a cost estimate of the difference in price between a three- and six-foot vegetative buffer, assuming that the buffer is located as marked in the site plan.

Response: The cost of the six-foot vegetative buffer is approximately double the cost of a three-foot vegetative buffer. Two quotes from landscapers who serve Metcalfe County for the amount of vegetative buffer marked on the site plan in Glover Creek's application are attached collectively as Confidential Exhibit 4. Please note that the cost of the vegetative buffer not only includes the initial cost of installation, but also includes civil work to prepare for plantings, replanting of any shrubs that die over time, and increased landscaping costs to maintain the vegetation around the buffer, and these additional costs are not included in the attached quotes.

f. Assuming the vegetative buffer is located as marked in the site plan and three- and six-foot trees were alternately planted in the buffer:

(1) Provide an estimate of the potential visual and noise reduction impact.

Response: The visual reduction impact of either three-foot or six-foot vegetative buffer will be to partially screen the project. Neither height will completely screen the project at the time of planting, and this is typical since it is optimal from a landscaping perspective to provide space around each planting to allow the shrubs to grow to a mature, healthy size without overcrowding.

The vegetative buffer will not generate a level of noise reduction that is audible to the human ear, as described in the letter from GAI Consultants attached as Exhibit 2. In order to help with noise impacts, the vegetative buffer would need to be significantly more robust and mature; the GAI letter references a buffer that is 100-feet wide and 30-feet tall in order to mitigate noise at a level that would be audible to the human ear. Such a substantial buffer would not be commercially feasible for solar development not only due to the amount of land required, cost of installation, and need for time for trees to grow to such height, but also because trees at that height would shade the solar panels, decreasing electrical output. For these reasons, Glover Creek suggests that the vegetative buffer should be used for visual impact reduction only, and not noise impact reduction. While Harvey Economics referred generally to a potential for noise impact reduction from a vegetative buffer, on further investigation, Glover Creek does not believe any vegetative buffer of the scope that is within the normal standards of the solar industry will assist with noise reduction.

(2) State whether the alternate buffer configuration would satisfy acceptable noise parameters.

Response: Glover Creek has proposed that acceptable noise parameters are 120 dBA at the property line. The project is able to meet this noise requirement without mitigation from any type of buffer.

Glover Creek's proposal is more restrictive than the industry standard, as suggested by Mid-Atlantic Renewable Energy Coalition (MAREC) in its public comment filed in this case that recommends a 120 dBA limitation at an occupied dwelling and only outside of normal business hours. Glover Creek is able to adhere to a more restrictive condition where noise is measured at the property line, but supports the MAREC comment and respectfully requests that the Siting Board consider each solar project application individually regarding noise conditions, which will likely be different at different project sites in Kentucky.

(3) Provide a cost estimate of the alternate buffer configuration.

Response: Glover Creek assumes that "the alternate buffer configuration" referenced in this question refers to a six-foot vegetative buffer. Two quotes from landscapers serving Metcalfe County for the amount of vegetative buffer marked on the site plan in Glover Creek's application at both three-foot and six-foot height are attached as Confidential Exhibit 4.

g. Confirm the planting of a 15-foot-wide vegetative buffer in the locations marked on the preliminary site plan filed in this matter by Glover Creek would address all known and identified visual and noise impacts from the solar facility.

Response: Glover Creek can confirm that based on our community and neighborhood consultation process, a 15-foot-wide vegetative buffer in the locations marked on the preliminary site plan filed in this matter would address all known and identified community and neighborhood concerns regarding impacts from the solar facility.

The proposed vegetative buffer would not shield the solar project from view from every location surrounding the project. However, as described in the Property Value Impact Report submitted with Glover Creek's application, solar projects do not have a deleterious impact on neighboring property values, are low to the ground (no more than 15-feet in height), and are similar in appearance to an industrial greenhouse. Therefore, the fact that the solar panels may be visible from parts of some neighboring properties does not mean that the project will have a negative impact on neighboring property values, or a negative impact generally.

[redacted]

As described above, the vegetative buffer will not address noise impacts; however the project is able to meet a requirement of 120 dBA at the property line without relying on a buffer.

Witness: Carson Harkrader

3. **Refer to Petition at page 7 regarding the temporary buffers suggested by Glover Creek. Provide additional information on the green slats and temporary canvas, such as a detailed description of each option, how each option would function, and the associated cost of installation and removal of each temporary option**.

Response: Carolina Solar Energy has experience with at least 2 solar projects where we have proposed that slats be placed within the chain link fence surrounding limited portions of the project in order to provide an additional visual buffer for neighbors who are particularly impacted by the solar project due to specific site characteristics. In these 2 examples, Carolina Solar Energy has proposed to install the slats in certain limited locations that have a specific visual impact. For example, at one project, the solar project surrounded a church on 3 sides of the church, and the church had a playground and social area in the back of the church property. Slats were installed in the fence in the areas where the project fence ran adjacent to the church property, in order to provide a visual buffer for the playground and social area. At another project, the project substation was adjacent to a residential home, and the slats were intended to provide a visual buffer for the home from the project substation while the planted buffer grew to maturity. Carolina Solar Energy met with these neighbors in both instances, and proposed the slats at those specific locations in response to those neighborhood meetings.

Slats are typically not removed from the fence, and are therefore a more permanent visual buffer solution. A cost estimate and technical specification for the slats is provided in Confidential Exhibit 5. Adding slats increases fencing costs by approximately fifty percent.

Carolina Solar Energy does not have experience with canvas being used as a visual buffer on the sites that we have developed. As described by GAI in their letter attached as Exhibit 2, slats and canvas are both ineffective at screening noise, nor implemented for that purpose.

Witness: Carson Harkrader

4. Refer to Glover Creek's Petition at page 9.

a. Provide additional information and support for the statement that "[s]cheduling all of the tamping near residences within 1,500 feet at the end of the tamping process will be inefficient and likely to cause increased costs, delays, or other unintended consequences during construction with uncertain benefit to the community.

Response: In order to see a visual image of what this would entail, please refer to the map attached as Exhibit 6. The shaded areas encompass all the sections of the solar project that are within 1,500 feet of a neighboring residential home. As you can see, there is a small, oddly shaped area in the center of the project site that is outside of the shaded area (the "Center Section".) On Glover Creek's site plan you can see that there is a farming area in the middle of the Center Section. We are currently planning to avoid putting solar panels on this farming area, at the request of the landowner, so that he can continue to use the farming infrastructure. Additionally, there are 3 separate streams that cross the Center Section.

In order to comply with the Siting Board's proposed condition as we interpret it, Glover Creek would need to kick off the installation of the racking posts in the Center Section, working around the farming area and streams, and finish the work in the Center Section prior to proceeding to install posts in the remainder of the project site. Installing the posts in only the Center Section, while avoiding the rest of the project site, may be inefficient due to the multiple constraints (farming area and streams) in the Center Section. This inefficiency will increase cost and create delays. In other words, it is likely to be more efficient from both a cost and time perspective to install the posts in the Center Section together with posts in surrounding sections.

Another issue that may occur is that typically, racks are installed in different sections of the site in a planned way, with the installation crew and pile drivers working from one section to another. The sections are scheduled for installation based on weather conditions and ground conditions (e.g., mud, potential for erosion, ongoing civil work, etc. in each of the different sections) in different parts of the site. If conditions on the ground are not optimal to start post installation in the Center Section when post installation is scheduled to begin, the Siting Board's condition would require Glover Creek to delay post installation on the remainder of the project site until conditions allow for installation of posts in the Center Section. This delay could increase cost and cause other unintended consequences such as inability to move equipment out of the loading area so that new equipment can be delivered, because the posts are not able to be installed on schedule. In other words, if there were no limitation from the Siting Board permit on where to start post installation, the construction manager would divide the project into sections in the most efficient way, and schedule post installation based on the sections of the project site that are ready to receive posts. Not allowing for this flexibility will create inefficiency and delays, which could in turn cause delays in meeting timeline obligations under interconnection agreements with the utility or agreements with the power purchaser (these are the unintended consequences).

Regarding benefit to the community, Glover Creek is not opposed to conditions which would have a positive and material impact on the neighboring community, and importantly, which would address any stated community concerns. It is unclear to us why scheduling installation of the posts in certain parts of the site last would have a positive impact on the project's neighbors because the posts will need to be installed throughout the project site sooner or later regardless. Installing the posts closer to neighbors at the end of the process of installing posts will not make the installation of the posts any less noisy for those neighbors, and in fact may increase the impact on them by stretching out the construction period due to inefficiency.

b. Explain whether Glover Creek has investigated what time during the working day would be optimal for the tamping process to occur in order to mitigate as much noise impact as possible to nearby property owners.

Response: GAI Consulting has addressed this issue at the end of their letter attached as Exhibit 2. Their conclusion is that noise would appear louder to neighbors between the nighttime hours of 10pm-7am. These hours are outside of the proposed construction hours proposed by Glover Creek of 7am-9pm, and therefore we believe that Glover Creek's proposed hours will mitigate as much noise impact as possible to nearby property owners.

Witness: Carson Harkrader

5. Refer to Glover Creek's Petition at page 10.

a. Provide additional information and support for the claim that limiting the construction activity, process, and deliveries to the hours of 8 a.m. to 6 p.m. Monday through Saturday would place substantial restriction on Glover Creek's ability to meet operational and construction deadlines.

Response: Solar projects face non-negotiable construction deadlines that carry stiff penalties for non-compliance. The deadlines typically come from at least three sources, including:

- Utility deadlines. Typically, the utility has been contracted to interconnect the project to its transmission grid, via an existing local transmission line, at a certain time. The utility must schedule an outage on its transmission line in order to connect the project. If the project is not completed construction and ready to be interconnected on time for the scheduled outage, the project may face financial penalties under the utility interconnection agreement, and if the scheduled outage is not able to be rescheduled, the project may face additional delays until a new scheduled outage can be scheduled to interconnect the project. Typically, utilities prefer to schedule outages in the spring and fall. If the appropriate time of year is missed, the resulting delay can delay the project's grid connection by months.
- Power contract deadlines. The contract with the company that will buy electricity and renewable energy credits from the solar project may include deadlines with associated financial or other penalties if the project is not able to deliver electricity and renewable energy credits on schedule.

- Tax deadlines. Solar projects in the US typically utilize the federal Investment Tax Credit (ITC). Projects must be placed in service by certain year-end deadlines and commence exporting power to the grid in order to qualify for various levels of tax credit. Missing a tax credit deadline, for a percentage of tax credit that was anticipated by the project, can have a very material impact on project economics.

In contrast to these non-negotiable deadlines, solar project developers face numerous events outside of their control including but not limited to the weather, sourcing delays, shipping delays, changes in availability and skill level of local labor, and other unforeseen national and international events. It is very important for solar developers to have the flexibility to ramp up the pace of construction in order to keep schedules on track. Solar project installation is complex and expensive. Once a project is installed, the sunshine is free; most of the cost of the electricity generated by solar projects comes during construction and installation.

Especially in the summertime when it is light later into the evening, solar developers will rely on being able to work into the evening in order to make up time if needed in order to meet project deadlines. Without this ability, a project that falls behind scheduled due to unforeseen events may face substantial penalties. Construction companies bidding to build the project may increase their bid pricing in order to ensure they are able to meet project deadlines, if there are unusually restrictive working hours such as those in the current Siting Board conditions.

Additionally, a conservative limit on construction working hours places a regulatory burden on solar projects that does not apply to other types of construction in Kentucky. Since there was no concern voiced by the Metcalfe County community and neighbors of the Glover Creek project about construction noise, MAREC members voiced concern in their letter that the precedent created in this permit would apply to other solar projects in Kentucky going forward. This would penalize Glover Creek and the solar industry. Since there is no noise ordinance that applies in Metcalfe County, Glover Creek respectfully requests approval for the proposed working hours of 7am to 9pm daily. Of benefit to the community, these hours will allow Glover Creek to complete the construction process in the most efficient timeline possible. Since time equals money in construction, Glover Creek has a strong incentive to complete construction in the shortest timeline reasonably possible.

b. Based upon the Glover Creek developer's experience with similar projects, explain the nature of the activity that will take place between the hours of 6 p.m. and 9 p.m.

Response: Evening hours could be used to make up time for any portion of work that faces delays. Glover Creek proposes no restrictions on construction activities during these hours. Restrictions placed on working hours and on the type of work that is able to be completed during working hours will add would place substantial restriction on Glover Creek's ability to meet operational and construction deadlines and may also increase Glover Creek's construction costs, as described above.

Witness: Carson Harkrader

6. Refer to the Petition at page 14 regarding these statements: "If the standard is based on noise measured at the noise generator, it could severely impact the viability of solar projects in Kentucky, including the [Glover Creek] Project. Rather, it is more appropriate to have a standard based on the noise receptor and not the noise generator." Provide additional information and support for these two statements.

Response: The reason for the first statement is that pile drivers are anticipated to generate noise that is 101 dB at 50 feet away from the source, which extrapolates to 120 dB at the source. While the anticipated noise level is 120 dB at the source, it may be louder on certain sites with certain soil conditions, or with certain individual pile drivers. Placing a requirement of 120 dB at the source gives the solar construction manager no room for error, which is deeply concerning given that it is impossible to measure in advance the noise that each individual pile driver will generate while operating in the different soil conditions across a solar project site. It would consume considerable time and resources, and create significant risk which the construction contractor will price into their contract and pass onto the project owner, in order to ensure compliance with this condition.

The reason for the second statement is that Glover Creek respectfully suggests that measuring noise at the noise generator does not provide benefit to the surrounding neighbors and community. The neighbors of the project will, we expect, be concerned about the noise they experience on their properties. Due to safety requirements, they will have no access to the solar project site and no reason to experience the noise levels generated at the source. Therefore, Glover Creek proposes that the Siting Board permit condition apply to noise at the noise receptor

(Glover Creek proposes this be the property line), which is the nearest point where the noise will be experienced by the project's neighbors.

Witness: Carson Harkrader

Exhibit List

Exhibit 1 - Images of projects with and without a vegetative buffer

Exhibit 2 – GAI Consultants Letter

Exhibit 3 – MCEC Study

Exhibit 4 – Vegetative Buffer Cost Quotes (confidential)

Exhibit 5 – Fencing and Slat Cost Quotes (confidential)

Exhibit 6 – Project Map

Exhibit 1 - Images of projects with and without a vegetative buffer

Image 1: A solar farm in Western NC. Buffer shown in a single row of 3-4ft tall evergreen trees. Image from Google Streetview.

Image 2: Solar farm in Rutherford County, outside of Forest City, NC. Buffer shown is a single row of 3-6ft evergreen trees. Image from Google Streetview.

Image 3: Solar farm in Franklin County, outside of Louisburg, NC. Image shown without a vegetative buffer from approximately 150ft from solar panels.

Image 4: Solar farm in Orange County, outside of Mebane, NC. Buffer shown is an alternating row of evergreen trees approximately 6-7ft tall. Image from Google Streetview.

Image 5: Solar farm in Orange County, outside of Mebane, NC. Buffer shown is mature, 9-12ft evergreen trees in alternating rows. This image was taken in January 2021 from the same solar project as Image 4, however the trees have grown larger.

Image 6: Solar Farm in Johnson County, outside of Selma, NC. Buffer shown is mature, 10-12ft evergreen bushes. Image from Google Streetview.

Exhibit 2 – GAI Consultants Letter

gai consultants

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January 14, 2021

Project R200785.03

Mr. Tyler Boquet-Caron
Solar Developer
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Response to Comments
Glover Creek Solar, LLC

Dear Mr. Boquet-Caron:

At the request of Glover Creek Solar, LLC (Glover Creek), GAI Consultants, Inc. (GAI) has prepared the following documentation and professional opinions related to the questions and comments provided by the Commonwealth of Kentucky and within the document titled SITING BOARD STAFF'S FIRST REQUEST FOR INFORMATION ON REHEARING TO GLOVER CREEK SOLAR, LLC. These responses pertain solely to any comments or questions related to sound levels, the anticipated impacts of sound level sources, and associated sound mitigation measures.

Item 2.c.

Comment:

Provide an explanation as to what would be considered an industry best practice as it relates to planting vegetative buffers to mitigate against noise and visual issues.

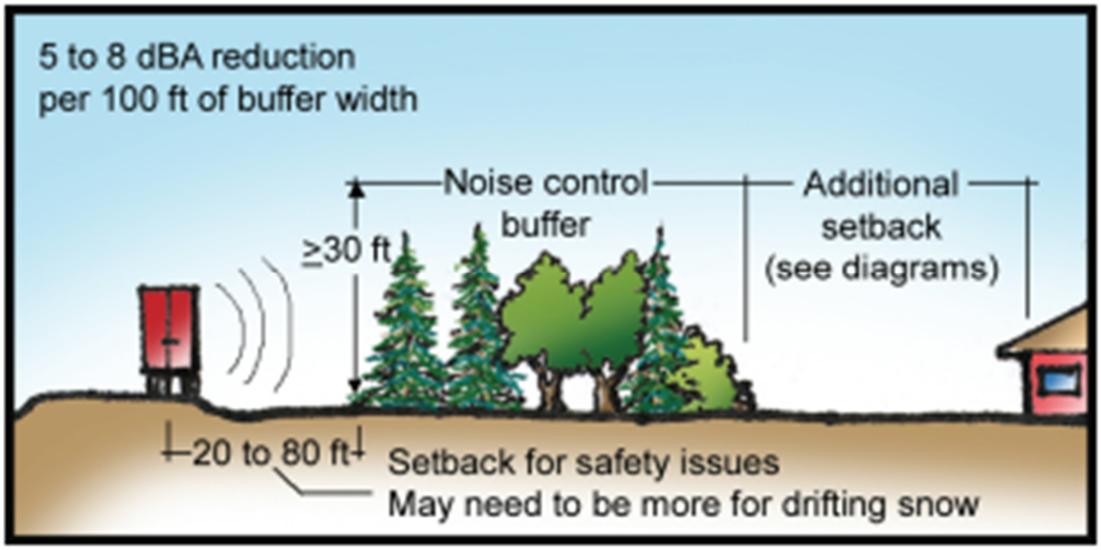
Response:

Vegetative buffers in the solar industry are, in general, used more for their visual aesthetics. Their suitableness as mitigation of potential noise impacts is less effective. This is because the depth of vegetative buffer required to obtain a substantial reduction in sound levels is large.

For example, “substantial” noise reduction is defined by the Federal Highway Administration (FHWA) as 5-10 dBA in paragraph 722.11d (Noise Abatement) of the Highway Traffic Noise Analysis and Abatement Policy and Guidance document (provided as reference). The Department of Housing and Urban Development (HUD) under 24 CFR § 51.103 (provided as reference) also defines a similar standard of 5 dBA or 10 dBA level of sound attenuation for “Normally Unacceptable” noise zones depending on the day-night sound level averages.

As an illustration of the effectiveness of vegetative buffers with regards to sound reduction, GAI has provided further information in the form of an USDA Forestry Service Data Sheet on the noise reduction from vegetative buffers. This information is being provided for reference in lieu of comprehensive qualitative modeling. In GAI’s professional experience, the data as provided by the above resources (i.e., the USDA Forestry Service document, etc.) is what would be expected when applied to real world applications.

A 100 feet of vegetative buffer (at greater than 30 feet in height) provides an estimated 5 to 8 dBA reduction of sound levels.



(figure extracted from attached reference USDA Forestry Service Data Sheet)

This further assumes that the length and overall design (i.e., shape, height, orientation, etc.) of the buffer also sufficiently extends beyond the referenced receptor's boundaries and provides adequate shielding at the edges to help mitigate sound propagation over and around the extents of the vegetative barrier. The factors contributing to adequate sound attenuation from any type of buffer is based on variable conditions (e.g. terrain, meteorological conditions, leaf cover) and is generally highly project and site specific. These considerations generally apply to all types of mitigation barriers, including vegetative buffers discussed herein.

Item 2.f.

Comment:

Assuming the vegetative buffer is located as marked in the site plan and three- and six-foot trees were alternatively planted in the buffer:

(1) Provide an estimate of the potential visual and noise reduction impact.

Response:

A 15-foot-deep vegetative buffer at either six- or three-foot in height is anticipated to provide minimal noise mitigation for a sensitive receptor. As described in the figure above, we can expect a 5 to 8 dBA reduction in sound levels per 100 feet of vegetative buffer width, assuming a vegetative buffer that is at least 30 feet tall. A double row of shrubs, whether six- or three-foot in height, would have less than a 3 dBA reduction in sound levels. Since the human ear cannot distinguish differences in noise below 3 dBA, neither a six- or three-foot vegetative buffer would reduce the noise experienced by neighbors of the solar project.

Comment:

(2) State whether the alternate buffer configuration would satisfy acceptable noise parameters.

Response:

The depth of vegetative buffers of the requested depth and either height would be generally ineffective at sound mitigation. However, it may be that Glover Creek is able to achieve acceptable noise parameters without sound mitigation. That question is outside the scope of this document.

Item 2.g.

Comment:

Confirm the planting of a 15-foot-wide vegetative buffer in the locations marked on the preliminary site plan filed in this matter by Glover Creek would address all known and identified visual and noise impacts from the solar facility.

Response:

In general, vegetative buffers of the depth and height discussed are not sufficient to significantly impact noise levels. This statement is based on GAI's professional opinion, previous experience with sound level monitoring and modeling, and the provided USDA Forestry Service Datasheet.

Item 3.

Comment:

Refer to the Petition at page 7 regarding the temporary buffers suggested by Glover Creek. Provide additional information on the green slats and temporary canvas, such as a detailed description of how each would function, and the associated cost of installation and removal of each option.

Response:

Specifically, and with regards to function related to noise, fencing consisting of green slats or temporary canvas will generally have minimal impact on sound levels. Slatted green fencing generally contains sufficient gaps and allows sound to readily traverse through the barrier with minimal impedance.

Item 4.b.

Comment:

Explain whether Glover Creek has investigated what time during the working day would be optimal for the tamping process to occur in order to mitigate as much noise impact as possible to nearby property owners.

Response:

In general, time of day has little to no effect on noise impact, with one notable exception. It is generally stated that, during nighttime hours, when fewer sources of ambient sound tend to exist, and when those sources that do exist tend to have a decreased impact (i.e., lesser traffic on roadways, etc.) the human ear is more sensitive to changes in sound levels.

This results in considering a 10 dBA "penalty" during these nighttime hours to equate nighttime sound levels to their daytime counterparts. The use of a 10 dBA penalty has been established for use by many federal and state agencies. For example, the USEPA establishes such a standard for a variety of project types including Airports (FAA Order 1050.1E) and the Federal Energy Regulatory Commission (FERC) establishes this standard for certain projects related to natural gas development.

Nighttime is defined as 10:00:00 PM to 6:59:59 AM. By correlation, daytime is defined as 7:00:00 AM to 9:59:59 PM. See attached reference Introduction to Noise Analysis Day-Night Sound Level (page 5 section 1.4.4)

While conditions that affect the migration of sound do change throughout the daytime hours, meteorological changes (temperature, humidity, fog, rain events, etc.) are the largest contributing factors to such changes. However, these are variable and unable to be predicted with any certainty with sufficient accuracy. As such, sound levels are generally considered to be constant and not as a variable if a source is continuously operating during the course of a day and assuming no change in load during daylight hours for the purpose of sound levels produced.

References

Highway Traffic Noise Analysis and Abatement Policy and Guidance Regulations 722.11d (Noise Abatement)

HUD 24 CFR Subpart B - Noise Abatement and Control 24 CFR § 51.103 - Criteria and standards.

USDA Forestry Service Data Sheet 6.4 Buffers for noise control

Introduction to Noise Analysis Day-Night Sound Level (page 5 section 1.4.4)

Glover Creek and GAI thank you in advance for your review of this additional information. Should you have any questions or comments, please feel free to contact me at 412.399.5274.

Sincerely,

GAI Consultants, Inc.

Jeffrey J. Jackson

Digitally signed by Jeffrey J. Jackson
DN: E=J.Jackson@gaiconsultants.com, CN=Jeffrey J. Jackson
Date: 2021.01.15 07:05:48-05'00'

Jeff J. Jackson, MS EnvE, P.E. (PA)
Sr. Project Engineer

JJJ/djz

Highway Traffic Noise Analysis and Abatement Policy and Guidance

772.11: NOISE ABATEMENT

a. In determining and abating traffic noise impacts, primary consideration is to be given to exterior areas. Abatement will usually be necessary only where frequent human use occurs and a lowered noise level would be of benefit.

b. In those situations where there are no exterior activities to be affected by the traffic noise, or where the exterior activities are far from or physically shielded from the roadway in a manner that prevents an impact on exterior activities, the interior criterion shall be used as the basis of determining noise impacts.

In most situations, if the exterior area can be protected, the interior will also be protected. The selection of the exterior area where "frequent human use occurs" is very important. This requires a site visit to determine whether people are using the entire exterior area or only a small portion, like a patio or porch. Some States choose the right-of-way line (a point farthest away from a house) to be on the conservative side when doing the noise impact analysis. Interior use applies mostly to hospitals and schools.

Interior noise level predictions may be computed by subtracting from the predicted exterior levels the noise reduction factors for the building in question. If field measurements of these noise reduction factors are obtained or the factors are calculated from detailed acoustical analyses, the measured or calculated reduction factors should be used. In the absence of such calculations or field measurements, the noise reduction factors may be obtained from the following table:

Table 7: Building Noise Reduction Factors
Noise Reduction Due to Exterior of the

Building Type	Window Condition	Structure
All	Open	10 dB
Light Frame	Ordinary Sash (closed)	20 dB
	Storm Windows	25 dB
Masonry	Single Glazed	25 dB
Masonry	Double Glazed	35 dB

NOTE: The windows shall be considered open unless there is firm knowledge that the windows are in fact kept closed almost every day of the year.

c. If a noise impact is identified, the abatement measures listed in paragraph 772.13c of this directive must be considered.

This self-explanatory paragraph requires consideration of noise abatement when noise impacts occur. As noted in paragraph 772.5g, noise impacts occur when noise levels approach or exceed the noise abatement criteria or when predicted levels substantially exceed existing levels. Consequently, this paragraph requires consideration of noise abatement for both of these types of noise impacts.

d. When noise abatement measures are being considered, every reasonable effort shall be made to obtain substantial noise reductions.

Abatement must provide at least a 5 dBA reduction in highway traffic noise levels in order to provide noticeable and effective attenuation. When noise abatement is proposed, it is recommended that an attempt be made to achieve the greatest reduction possible. SHAs have generally defined substantial reduction to be in the range of 5-10 dBA.

This paragraph does not say to reduce to the noise abatement criteria; it says "substantial noise reductions." Consequently, a projected noise level of Leq 69 for a Category B activity (see Table 5) should not be abated merely to the noise abatement criterion of Leq 67, but rather a substantial reduction should be obtained (at least 5 dBA). The choice of what minimum reduction to strive for is certainly a subjective one and is probably related to data found in technical literature, such as the following table.

Table 8: Relationship Between Decibel, Energy, and Loudness

A-Level Down	Remove % of Energy	Divide Loudness by
3 dBA	50	1.2
6 dBA	75	1.5
10 dBA	90	2
20 dBA	99	4

A reduction of 10 dBA (say 75 dBA to 65 dBA) will be perceived by the public as a halving of the loudness. This is an easily recognizable change. 5 dBA and 7 dBA changes can also be recognized, but to a lesser degree. Two points should be kept in mind: (1) any reduction will improve the noise environment in such areas as annoyance, speech interference, task interference, etc., and (2) no matter what the reduction, until the level reaches a very low level (about Leq = 55 dBA), the noise environment will continue to be dominated by traffic noise that is clearly audible.

e. Before adoption of a final environmental impact statement or finding of no significant impact, the highway agency shall identify:

1. noise abatement measures which are reasonable and feasible and which are likely to be incorporated in the project, and
2. noise impacts for which no apparent solution is available.

This paragraph ties the noise regulation to the NEPA requirements. An important point is that the requirements for the draft environmental impact statement (EIS) are the same as the final. Therefore, the information for both 772.11e(1) and 772.11e(2) are needed in the draft EIS and the final EIS. The choice of the word "likely" was deliberate. If a decisionmaker is to make an informed decision and if the public is to be made aware of the impacts, the State must make its intentions known. If the State later decides that mitigation is not warranted, the decision should have strong support. If the State would like to qualify the word "likely," this is acceptable. When a project involves consideration of more than one barrier, a statement of "likelihood" for each barrier should be included in the environmental document. The following is an illustration of some appropriate words.

Based on the studies so far accomplished, the State intends to install noise abatement measures in the form of a barrier at . These preliminary indications of likely abatement measures are based upon preliminary design for a barrier cost of $ that will reduce the noise level by dBA for residents. If it subsequently develops during final design that these conditions have substantially changed, the abatement measures might not be provided. A final decision of the installation of the abatement measure(s) will be made upon completion of the project design and the public involvement processes.

f. The views of the impacted residents will be a major consideration in reaching a decision on the reasonableness of abatement measures to be provided.

The views of the impacted residents should be a major consideration in determining the reasonableness of traffic noise abatement measures for proposed highway construction projects. The views should be determined and addressed during the environmental phase of project development. The will and desires of the general public should be an important factor in dealing with the overall problems of highway traffic noise. SHAs should incorporate traffic noise consideration in their on-going activities for public involvement in the highway program, i.e., the residents' views on the desirability and acceptability of abatement need to be reexamined periodically during project development.

g. The plans and specifications will not be approved by FHWA unless those noise abatement measures which are reasonable and feasible are incorporated into the plans and specifications to reduce or eliminate the noise impact on existing activities, developed lands, or undeveloped lands for which development is planned, designed, and programmed.

This is a summary statement of the requirements in the 1970 Federal-Aid Highway Act [23 U.S.C. 109(i)].

The key words in this paragraph are "reasonable" and "feasible." For a thorough explanation of reasonableness and feasibility of abatement, see the discussion on pp. 50-56.

24 CFR § 51.103 - Criteria and standards.

§ 51.103 Criteria and standards.

These standards apply to all programs as indicated in § 51.101.

(a) ***Measure of external noise environments.*** The magnitude of the external noise environment at a site is determined by the value of the day-night average sound level produced as the result of the accumulation of noise from all sources contributing to the external noise environment at the site. Day-night average sound level, abbreviated as DNL and symbolized as L_{dn}, is the 24-hour average sound level, in decibels, obtained after addition of 10 decibels to sound levels in the night from 10 p.m. to 7 a.m. Mathematical expressions for average sound level and day-night average sound level are stated in the Appendix I to this subpart.

(b) ***Loud impulsive sounds.*** On an interim basis, when loud impulsive sounds, such as explosions or sonic booms, are experienced at a site, the day-night average sound level produced by the loud impulsive sounds alone shall have 8 decibels added to it in assessing the acceptability of the site (see appendix I to this subpart). Alternatively, the C-weighted day-night average sound level (L_{Cdn}) may be used without the 8 decibel addition, as indicated in § 51.106(a)(3). Methods for assessing the contribution of loud impulsive sounds to day-night average sound level at a site and mathematical expressions for determining whether a sound is classed as "loud impulsive" are provided in the appendix I to this subpart.

(c) ***Exterior standards.***

(1) The degree of acceptability of the noise environment at a site is determined by the sound levelsexternal to buildings or other facilities containing noise sensitive uses. The standards shall usually apply at a location 2 meters (6.5 feet) from the building housing noise sensitive activities in the direction of the predominant noise source. Where the building location is undetermined, the standards shall apply 2 meters (6.5 feet) from the building setback line nearest to the predominant noise source. The standards shall also apply at other locations where it is determined that quiet outdoor space is required in an area ancillary to the principal use on the site.

(2) The noise environment inside a building is considered acceptable if: (i) The noise environment external to the building complies with these standards, and (ii) the building is constructed in a manner common to the area or, if of uncommon construction, has at least the equivalent noise attenuation characteristics.

SITE ACCEPTABILITY STANDARDS

	Day-night average sound level (in decibels)	Special approvals and requirements
Acceptable	Not exceeding 65 dB(1)	None.
Normally Unacceptable	Above 65 dB but not exceeding 75 dB	Special Approvals (2)
		Environmental Review (3).
		Attenuation (4).
Unacceptable	Above 75 dB	Special Approvals (2).
		Environmental Review (3).
		Attenuation (5).

Notes: (1) Acceptable threshold may be shifted to 70 dB in special circumstances pursuant to § 51.105(a).

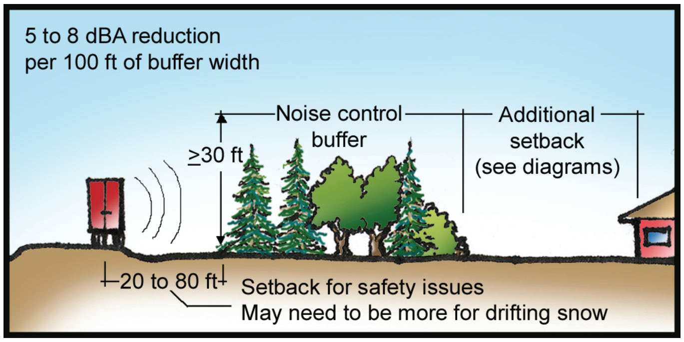
(2) See § 51.104(b) for requirements.

(3) See § 51.104(b) for requirements.

(4) 5 dB additional attenuation required for sites above 65 dB but not exceeding 70 dB and 10 dB additional attenuation required for sites above 70 dB but not exceeding 75 dB. (See § 51.104(a).)

(5) Attenuation measures to be submitted to the Assistant Secretary for CPD for approval on a case-by-case basis.

[44 FR 40861, July 12, 1979, as amended at 49 FR 12214, Mar. 29, 1984]



6.4 Buffers for noise control

Buffers can reduce noise from roads and other sources to levels that allow normal outdoor activities to occur. A 100-foot wide planted buffer will reduce noise by 5 to 8 decibels (dBA). Using a barrier in the buffer such as a landform can significantly increase buffer effectiveness (10 to 15 dBA reduction per 100-foot wide buffer with 12-foot high landform).

Guidelines are provided below for roads. Use the diagrams on the adjacent page to estimate a setback distance from a typical 100-foot wide buffer to achieve an acceptable noise level.

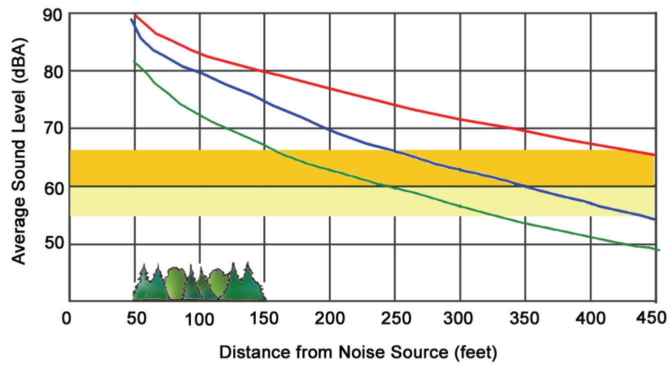
Buffer Guidelines for Noise Reduction Along Roads	
Moderate Speed Road (<40 mph)	**High Speed Road (≥40 mph)**
Plant a 20 to 50-foot wide buffer with the near edge of the buffer within 20 to 50 feet of the center of the nearest traffic lane	Plant a 65 to 100-foot wide buffer with the near edge of the buffer within 50 to 80 feet of the center of the nearest traffic lane

Key design considerations

- Locate buffer close to the noise source while providing an appropriate setback for accidents and drifting snow.
- Evergreen species will offer year-around noise control.
- Create a dense buffer with trees and shrubs to prevent gaps.
- Select plants tolerant of air pollution and de-icing methods.
- Natural buffers will be less effective than planted buffers.
- Consider topography and use existing landforms as noise barriers where possible.

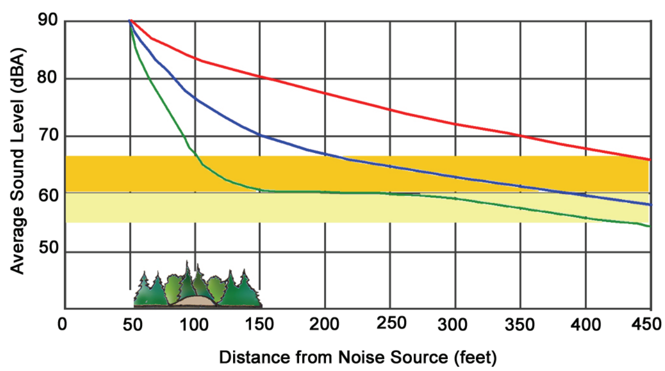
Estimating setback distance from noise control buffers
Example: An outdoor recreational site near a highway needs to be located to meet the desired noise levels of 60 to 65 dBA. If 100-ft wide tree/shrub buffer is used, the site needs to be 100 to 200 feet behind the buffer. The site can be located immediately behind the buffer if a 12-ft high landform is incorporated into the buffer.

Sound Level Decrease with Distance Due to Tree/Shrub Buffer



Control - (No tree/shrub buffer - truck noise at 55 mph)
Truck noise with 100-ft wide tree/shrub buffer
Car noise with 100-ft wide tree/shrub buffer

Sound Level Decrease with Distance Due to Tree/Shrub and Landform Buffer



Control - (No tree/shrub buffer - truck noise at 55 mph)
Truck noise with 100-ft wide tree/shrub buffer & 4-ft high landform
Truck noise with 100-ft wide tree/shrub buffer &12-ft high landform

60 to 65 dBA acceptable noise levels for outdoor conversation
55 to 60 dBA acceptable noise levels for daytime residential areas

6.4 References

Anderson, L.M.; Mulligan, B.E.; Goodman, L.S. 1984. Effects of vegetation on human response to sound. Journal of Arboriculture. 10: 45-49.

Aylor, D.E. 1972. Noise reduction by vegetation and ground. Journal of the Acoustical Society of America. 51: 197-205.

Bullen, R.; Fricke, F. 1982. Sound propagation through vegetation. Journal of Sound and Vibration. 80: 11-23.

Cook, D.I.; Haverbeke, D.F.V. 1971. Trees and shrubs for noise abatement. Bulletin RB246. Lincoln, NE: University of Nebraska, College of Agricultural Experimental Station. 77 p.

Cook, D.I.; Haverbeke, D.F.V. 1972. Trees, shrubs, and landforms for noise control. Journal of Soil and Water Conservation. 27: 259-261.

Cook, D.I.; Haverbeke, D.F.V. 1974. Tree-covered land-forms for noise control. Bulletin RB263. Lincoln, NE: University of Nebraska, College of Agricultural Experimental Station. 52 p.

Cook, D.I.; Haverbeke, D.F.V. 1977. Suburban noise control with plant materials and solid barriers. Bulletin EM100. Lincoln, NE: University of Nebraska, College of Agricultural Experimental Station Bulletin. 74 p.

Embleton, T.F.W. 1963. Sound propagation in homogeneous deciduous and evergreen woods. Journal of the Acoustical Society of America. 35: 1119-1125.

Fang, C.F.; Ling, D.L. 2003. Investigation of the noise reduction provided by tree belts. Landscape and Urban Planning. 63: 187-195.

Fang, C.F.; Ling, D.L. 2005. Guidance for noise reduction provided by tree belts. Landscape and Urban Planning. 71: 29-34.

Fricke, F. 1984. Sound attenuation in forests. Journal of Sound and Vibration. 92: 149-158.

Harris, R.A. 1985. Vegetative barriers: an alternative highway noise abatement measure. Noise Control Engineering Journal. 27: 4-8.

Harris, R.A.; Cohn, L.F. 1985. Use of vegetation for abatement of highway traffic noise. Journal of Urban Planning and Development. 111: 34-48.

Heisler, G.M. 1977. Trees modify metropolitan climate and noise. Journal of Arboriculture. 3: 201-207.

Kotzen, B. 2004. Plants and environmental noise barriers. Acta Horticulturae. 643: 265-275.

Kragh, J. 1979. Pilot study on railway noise attenuation by belts of trees. Journal of Sound and Vibration. 66: 407-415.

Kragh, J. 1981. Road traffic noise attenuation by belts of trees. Journal of Sound and Vibration. 74: 235-241.

Martens, M.J.M. 1981. Noise abatement in plant monocultures and plant communities. Applied Acoustics. 14: 167-189.

Reethof, G. 1973. Effect of plantings on radiation of highway noise. Journal of the Air Pollution Control Association. 23: 185-189.

Reethof, G.; Heisler, G.M. 1976. Trees and forests for noise abatement and visual screening. In: Gen. Tech. Rep. NE-22. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 39-48.

Reethof, G.; McDaniel, O.H.; Heisler, G.M. 1977. Sound adsorption characteristics of tree bark and forest floor. In: Gen. Tech. Rep. NE-25. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 206-217.

Whitcomb, C.D.; Stowers, J.F. 1973. Sound abatement with hedges. HortScience. 8: 128-129.

Appendix C.1 Noise

Contents

Introduction to Noise Analysis

Introduction to Noise Analysis

This introduction to the methods used for noise analysis provides an overview of aircraft noise measurement, noise compatibility guidelines, effects of noise exposure, and the Federal Aviation Administration's (FAA's) Integrated Noise Model (INM).

1. Noise Measurement

Noise is defined as unwanted sound. In other words, noise is sound that disturbs routine activities or quiet and/or causes feelings of annoyance. Whether sound is interpreted as pleasant or unpleasant depends largely upon the listener's current activity, experience, and attitude toward the source.

1.1 Characteristics of Sound

Sound is transmitted by alternating compression and decompression in air pressure. These relatively small changes in atmospheric pressure are called sound waves. The measurement and human perception of sound involves two physical characteristics—intensity and frequency. Intensity is a measure of the strength or magnitude of the sound vibrations, and is expressed in terms of the sound pressure level (SPL) measured in decibels. The higher the SPL, the more intense is the perception of that sound. The other characteristic is sound frequency, or "pitch," the speed of vibration. Frequencies are expressed in terms of cycles per second, or hertz (Hz). Low-frequency sounds might be characterized as a rumble or roar, while high-frequency sounds are typified by sirens or screeches. Noise analysis accounts for both intensity and frequency.

1.2 Decibel

The human ear is sensitive to an extremely wide range of sound intensity, which covers a relative scale of from 1 to 100,000,000. Representation of sound intensity using a linear index becomes difficult due to this wide range. As a result, the decibel (dB), a logarithmic measure of the magnitude of sound, is typically used. On the dB scale, the range of human hearing begins at 0 dB, which is approximately the threshold of hearing, to 130 dB, which is the threshold of pain.

Because it is a logarithmic unit of measurement, a decibel cannot be added or subtracted arithmetically; however, a number of simple rules of thumb are useful, as follows:

- If two sounds of the same level are added, the sound level increases by approximately 3 dB. For example: 60 dB + 60 dB = 63 dB.
- The sum of two sounds of a different level is only slightly higher than the louder level. For example: 60 dB + 70 dB = 70.4 dB.
- Sound from a "point source," such as an aircraft, decreases approximately 6 dB for each doubling of distance.

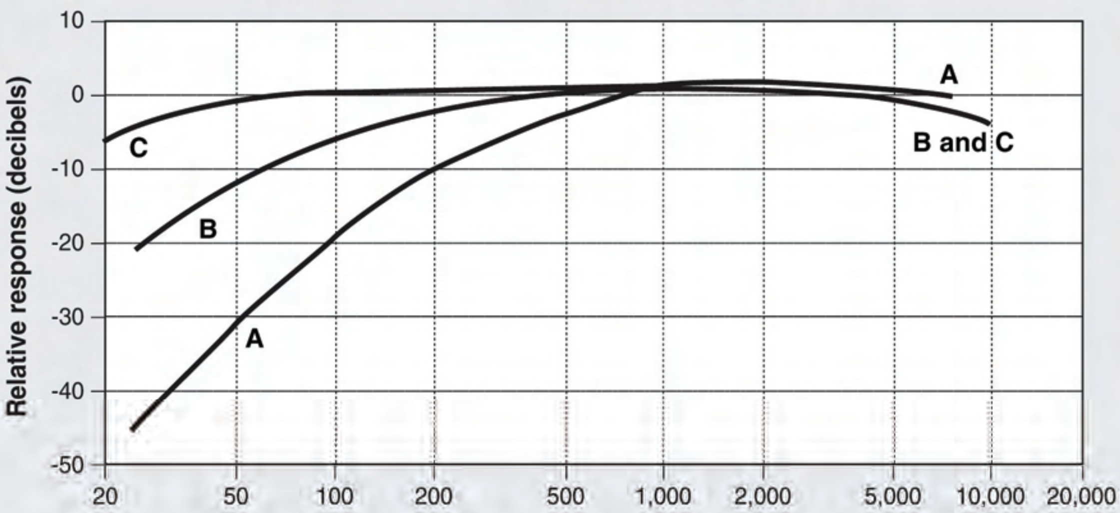
- Sounds from a “line source,” such as a roadway, decrease approximately 3 dB for each doubling of distance.
- Although the human ear can detect a sound as faint as 1 dB, the typical person does not perceive changes of less than approximately 3 dB.
- A 10-dB change in sound level is perceived by the average person as a doubling or halving of the sound’s loudness.

1.3 A-Weighted Decibel

Humans are most sensitive to frequencies near the normal range of speech communications. The “A-weighting” scale reflects this sensitivity by emphasizing mid-range frequencies and de-emphasizing high and low frequencies (see Figure 1). Because the A-weighted decibel (dBA) is a better predictor of human reaction to environmental noise than the unweighted decibel, it is used as the basis for the metrics most frequently used in noise compatibility planning (Chantlett, 1973).

Figure 1

NOISE METRICS—FREQUENCY RESPONSE



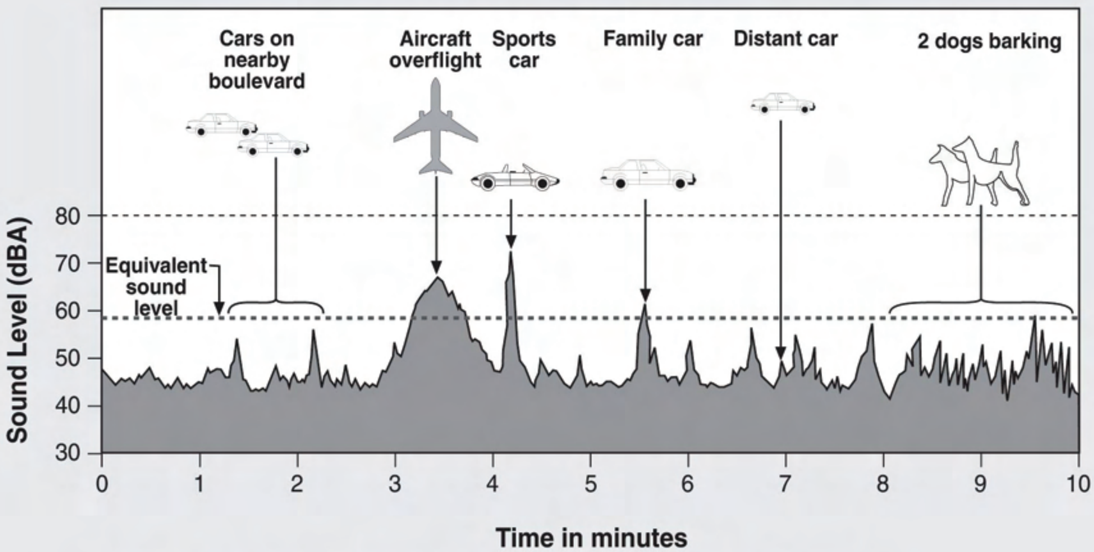
Source: A. Peterson and E. Gross, *Handbook of Noise Control*, West Concord: General Radio Company, 1967.

1.4 Additional Noise Metrics

The measurement of sound is not a simple task. Consider typical sounds in a suburban neighborhood on a normal or “quiet” afternoon. If a short history of those sounds is plotted on a graph, it would look very much like Figure 2. In Figure 2, the background or residential sound level in the absence of any identifiable noise sources is approximately 45 dB. During roughly three-quarters of the time, the sound level is 50 dB or less. The highest sound level, caused by a nearby sports car, is approximately 70 dB, while an aircraft generates a maximum sound level of about 68 dB. The following subsections provide a discussion of how variable community noise is measured.

Figure 2

NOISE METRICS—COMPARATIVE NOISE LEVELS



Source: *Protective Noise Levels, Condensed Version of EPA Levels Document,* United States Environmental Protection Agency, November 1978.

1.4.1 Maximum Sound Level

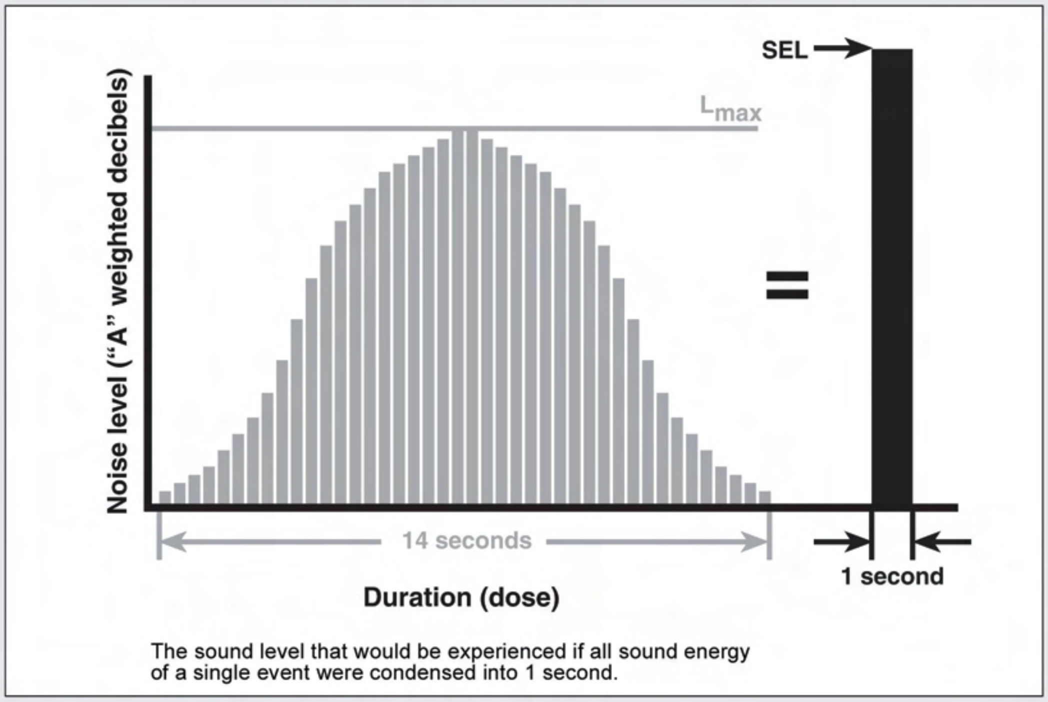
One obvious way of describing noise is to measure the maximum sound level (L_{max})—in the case of Figure 2, L_{max} would be the nearby sports car at 70 dBA. The maximum sound level measurement does not account for the duration of the sound. Studies have shown that human response to noise involves both the maximum level and its duration. For example, the aircraft in this case is not as loud as the sports car, but the aircraft sound lasts longer. For most people, the aircraft overflight would be more annoying than the sports car event. Thus, the maximum sound level alone is not sufficient to predict reaction to environmental noise.

1.4.2 Sound Exposure Level

Clearly, the longer a noise lasts, the more it disrupts activity and the more annoying it is likely to be. Laboratory tests indicate that the acceptability of noise decreases at a rate of roughly 3 dB per doubling of duration (Galloway, 1970). In other words, two sounds would be judged equally acceptable if one had an intensity of 3 dB more than the other, but half the duration of the other. Accordingly, a second manner of describing noise is to measure the sound exposure level (SEL), which is the total sound energy of a single sound event. By accounting for both intensity and duration, the SEL allows us to compare the "annoyance" of different events. One way to understand SEL is to think of it as the sound level you would experience if all of the sound energy of a sound event occurred in one second (Figure 3). This normalization to one second allows the direct comparison of sounds of different duration. In the sample time history on Figure 2, the sports car with maximum noise level of about 70 dBA generated an SEL of about 77 dB, while the aircraft with a maximum noise level of about 65 dBA generates an SEL of about 81 dB.

Figure 3

NOISE METRICS—SOUND EXPOSURE LEVEL (SEL)



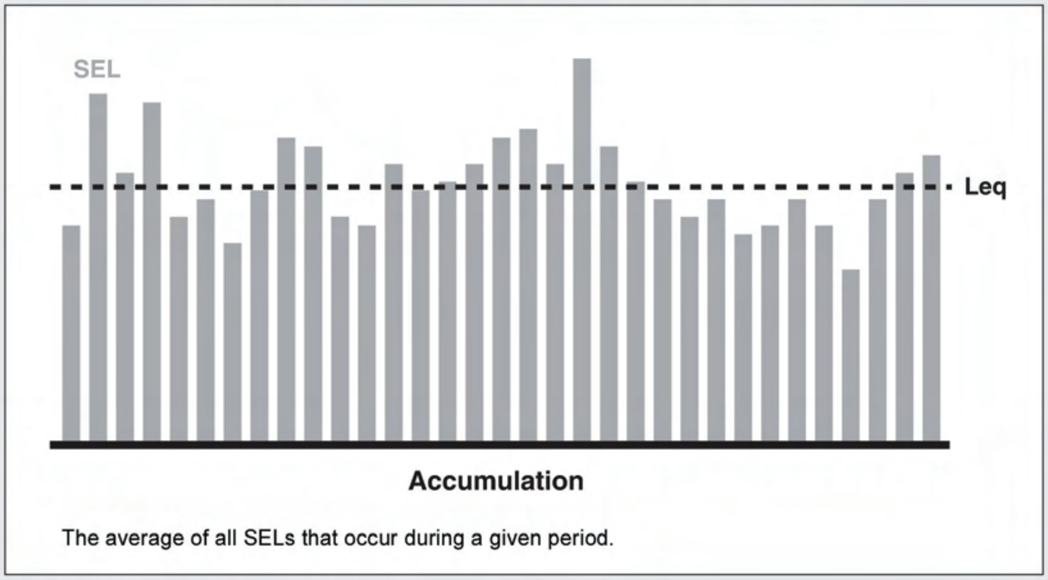
Source: CH2M HILL from multiple sources

1.4.3 Equivalent Sound Level

While L_{max} and SEL measure individual events, the number of events can also be an important consideration in estimating the effect of noise. One way to characterize the frequency of events is to count the number of events exceeding a specific sound level. Most often, the single event sound exposure levels of SEL 70 dBA, 75 dBA, and 80 dBA are used for such evaluations. A more efficient way to describe both the number of such events and the sound exposure level of each is the time-average of the total sound energy over a specified period (Figure 4), referred to as the equivalent sound level (L_{eq}). Research indicates that community reaction to noise corresponds to the total acoustic energy that is represented by the L_{eq}. In the example shown in Figure 4, the L_{eq} is roughly 56 dBA. This accounts for all of the sound energy during the sample period and provides a single-number descriptor.

Figure 4

NOISE METRICS—EQUIVALENT SOUND LEVEL (Leq)



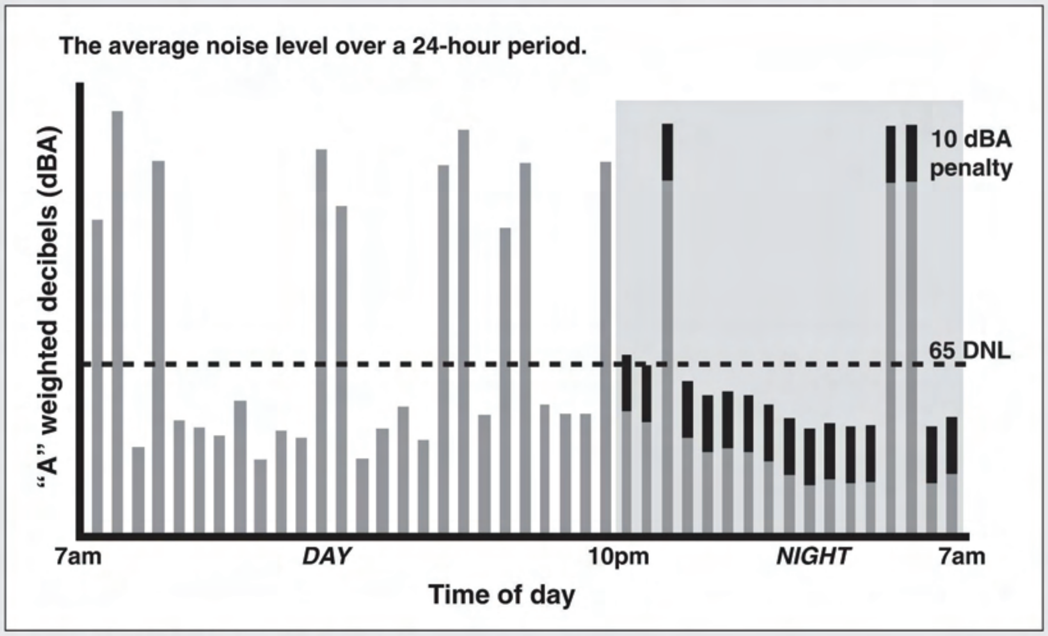
Source: CH2M HILL from multiple sources

1.4.4 Day-Night Average Sound Level

One additional factor is also important in measuring a sound—the occurrence of sound events that occur during nighttime hours. People are normally more sensitive to intrusive sound events at night, and the background sound levels are normally lower at night because of decreased human activity. Therefore, noise events during the nighttime (10:00:00 p.m. to 6:59:59 a.m.) are likely to be more annoying than noise events during the daytime (7:00:00 a.m. to 9:59:59 p.m.). To account for these factors, the day-night average sound level (DNL) adds a 10 dBA penalty to sound levels occurring during the nighttime (Figure 5). In essence, the DNL is the 24-hour equivalent sound level (or L_{eq} 24), including this 10-dB penalty. This 10-dBA penalty means that one nighttime sound event is equivalent to 10 daytime events of the same level. The DNL has been identified by the U.S. Environmental Protection Agency (EPA) as the principal metric for airport noise analysis (EPA, 1974). FAA Order 1050.1E, Change 1, requires the use of DNL for determining aircraft noise impacts for airport actions being evaluated under the National Environmental Policy Act (NEPA).

Figure 5

NOISE METRICS—DAY-NIGHT AVERAGE SOUND LEVEL (DNL)



Source: CH2M HILL from multiple sources

DNL is expressed as an average noise level on the basis of annual aircraft operations for a calendar year. To calculate the DNL at a specific location, SELs for that particular location are determined for each aircraft operation (landing or takeoff). The SEL for each operation is then adjusted to reflect the duration of the operation and arrive at a "partial" DNL for the operation. The partial DNL values are then added logarithmically—with the appropriate penalty for those operations occurring during the nighttime hours—to determine total noise exposure levels for the average day of the year.

The logarithmic addition process described earlier also applies to DNL. For example, an increase or decrease of DNL 3 dB would require either a doubling or halving of aircraft operations (assuming the same types of aircraft and the same proportion of nighttime activity). This same change of DNL 3 dB could also be achieved by an average change of 3 dB per aircraft operation. The formula for calculating this change is as follows:

10*Log(X/Y) = Z dB change

X = Future Traffic Volume

Y = Existing Traffic Volume

When X/Y = 2, Z = 3.0 dB, a doubling of traffic occurs which results in a 3-dB increase in noise.

A 1.5-dB (Z = 1.5 dB) increase in noise occurs when X/Y = 1.4, which indicates a 40 percent increase in traffic.

DNL is the required noise descriptor for quantifying existing and future noise exposure for communities in airport environs in most of the United States, and to estimate the effects of airport operations on land use compatibility. DNL has been widely accepted as the best available method to describe aircraft noise exposure and is the noise descriptor required by the FAA for use in aircraft noise exposure analyses and noise compatibility planning (FAA, 1984).

2. Noise Compatibility Guidelines

In most cases, the aircraft noise levels encountered in communities surrounding airports are below the levels associated with risk of hearing loss (EPA, 1974). Section 3, Effects of Noise Exposure, provides further discussion of the potential health effects of noise. At the levels typically encountered in airport environs, the major effect of aircraft noise is annoyance. As directed by Congress in the Aviation Noise and Safety Act of 1979 (ASNA), the FAA and other branches of the federal government have established guidelines for noise compatibility based on annoyance.

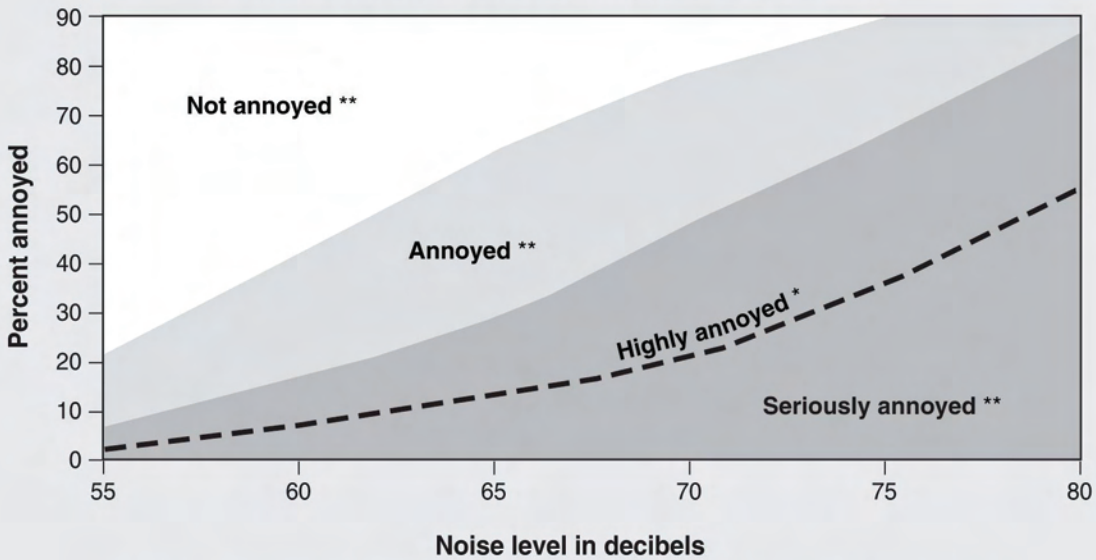
2.1 Community Annoyance

Although individual responses to environmental noise vary widely, extensive survey data demonstrate that community reaction to noise relates closely to cumulative noise exposure expressed in terms of DNL (Schultz, 1978). This relationship between DNL and community reaction has been used to establish federal guidelines for noise compatibility planning. As a result of these studies, the Federal Interagency Committee on Urban Noise (FICUN) established DNL 65 dB as the threshold of significant noise impact (FICUN, 1981). In 1990 the Federal Interagency Committee on Noise (FICON) re-validated the basic findings and recommendations of the FICUN with respect to noise compatibility analysis and thresholds of significant noise impact. Figure 6 shows the relationship between DNL and community response.

The FICON also recommended that supplemental noise analyses be considered to provide additional information in considering the effects of aircraft noise. For example, in considering the noise impacts of a proposed action, a DNL 1.5-dB increase in noise above DNL 65 dB at a "noise-sensitive land use" (see the following subsection) is considered to be "significant." In the event of a "significant" noise increase, FICON recommended that changes of DNL 3 dB above DNL 60 dB also be identified because such changes produce similar changes in community annoyance (see Figure 6).

Figure 6

NOISE METRICS—PERCENT OF PEOPLE ANNOYED



Sources: * Percentage of Residents Annoyed, Richard, E.J. and J.B. Ollerhead; reproduced in "Aviation Noise Effects," FAA Offices of Environment and Energy, March 1985.

** Schultz T.J. "Synthesis of Social Surveys on Noise Annoyance," *Journal of Acoustical Society of America*, 1978.

Experience in assessing the effects of airspace changes indicates that an increase of DNL 5 dB above ambient noise levels can lead to community reaction even below the threshold of significance. As a result of this experience, the FAA has established screening procedures to determine whether air traffic control actions taken at altitudes above 3,000 feet above ground level (AGL) would likely generate a change of DNL 5 dB or more above ambient noise levels (FAA, 1999). Accordingly, it is sometimes useful to identify changes of at least DNL 5 dB below DNL 60 dB. In considering the effects of noise below DNL 65 dB, it is important to consider the reduced reliability of noise modeling at lower noise levels (see Section 1.2 regarding noise modeling).

2.2 Land Use Compatibility Guidelines

In accordance with the ASNA, the principal purpose of noise compatibility planning under FAR Part 150 is to reduce noncompatible land use. The 1981 FICUN report identified noise compatibility guidelines for land use categories defined by the Standard Land Use Coding Manual. A simplified version of these guidelines is incorporated in FAR Part 150 (FAA, 1985) and is shown in Table 1. Although this table indicates that all land uses are considered to be compatible with noise levels below DNL 65 dB, the federal government does not control local land use, and units of local government exercising land use control may elect to establish more rigorous standards.

TABLE 1
Land Use Compatibility with Yearly Day-Night Average Sound Levels

Land Use	Yearly Day-Night Average Sound Level (DNL) (decibels)[a]					
	<65	65-70	70-75	75-80	80-85	> 85
Residential						
Residential, other than mobile homes and transient lodging	Y	N[b]	N[b]	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodging	Y	N[b]	N[b]	N[b]	N	N
Public use						
Schools	Y	N[b]	N[b]	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoriums, and concert halls	Y	25	30	N	N	N
Governmental services	Y	Y	25	30	N	N
Transportation	Y	Y	Y[c]	Y[d]	Y[e]	Y[e]
Parking	Y	Y	Y[c]	Y[d]	Y[e]	N
Commercial						
Offices, business, and professional	Y	Y	25	30	N	N
Wholesale and retail building materials, hardware, and farm equipment	Y	Y	Y[c]	Y[d]	Y[e]	N
Retail trade, general	Y	Y	25	30	N	N
Utilities	Y	Y	Y[c]	Y[d]	Y[e]	N
Communication	Y	Y	25	30	N	N
Manufacturing						
Manufacturing, general	Y	Y	Y[c]	Y[d]	Y[e]	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y[f]	Y[g]	Y[h]	Y[h]	Y[h]
Livestock farming and breeding	Y	Y[f]	Y[g]	N	N	N
Mining and fishing—resource production and extraction	Y	Y	Y	Y	Y	Y
Recreational						
Outdoor sports arenas and spectator sports	Y	Y[i]	Y[i]	N	N	N
Outdoor music shells and amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts, and camps	Y	Y	Y	N	N	N

TABLE 1
Land Use Compatibility with Yearly Day-Night Average Sound Levels

Land Use	Yearly Day-Night Average Sound Level (DNL) (decibels)[a]					
	<65	65-70	70-75	75-80	80-85	> 85
Golf courses, riding stables, and water recreation	Y	Y	25	30	N	N

[a] Y (Yes) = Land use and related structures compatible without restrictions.
N (No) = Land use and related structures are not compatible and should be restricted.
NLR = Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure.
25, 30, or 35 = Land use and related structure generally compatible; measures to achieve NLR of 25, 30, or 35 dB must be incorporated into design and construction of structure.

[b] Where the community determines that residential or school uses must be allowed, measures to achieve outdoor-to-indoor noise level reduction (NLR) of at least 25 to 30 dB should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide an NLR of 20 dB; thus, the reduction requirements are often stated as 5, 10, or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year round. However, the use of NLR criteria will not eliminate outdoor noise problems.

[c] Measures to achieve NLR 25 dB should be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or the normal level is low.

[d] Measures to achieve NLR 30 dB should be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or the normal level is low.

[e] Measures to achieve NLR 35 dB should be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or the normal level is low.

[f] Residential buildings require an NLR of 25.

[g] Residential buildings require an NLR of 30.

[h] Residential buildings not permitted.

[i] Land-use-compatible-provided special sound reinforcement systems are installed.

Source: FAA Federal Aviation Regulations (FAR) Part 150, Table 1.

3. Effects of Noise Exposure

The previous section focused on community annoyance and the resultant land use compatibility guidelines established for noise compatibility planning under FAR Part 150. As noted in that section, annoyance is the primary factor considered in aircraft noise compatibility analysis. Other factors include potential health effects and the effects of noise and vibration on structures. This section reviews these potential noise effects and the noise metrics typically used to assess them.

3.1 Effect of Noise Exposure on People

Over the last 45 years, researchers have identified many of the factors contributing to human reaction to noise (Newman and Beattie, 1985). These effects include annoyance due to speech interference, potential hearing loss, and non-auditory health effects. Research indicates that the psychological impact of aircraft noise may be a more serious concern than direct physical impacts. Studies conducted in the late 1960s and early 1970s found that the interruption of communication, rest, relaxation, and sleep are important causes for complaints about aircraft noise. Disturbance of television viewing, radio listening, and telephone conversations are also sources of serious annoyance. A review of these effects follows.

3.1.1 Effects on Communication

Interference with speech communication, television and radio listening, and classroom teaching are among the most frequently cited problems associated with aircraft noise. To a large extent, these factors are responsible for community annoyance as described in the previous section. Figure 7 summarizes the results of research into speech interference associated with various noise intensities and communications distances. The 1992 FICON report (FICON, 1992) indicates that, whenever noise levels exceed approximately 60 dBA, there will be interference with speech communication. Assuming that typical residential construction provides 15 to 25 dBA of sound attenuation (windows open or closed, respectively), the FICON report concluded that some degree of interior speech interference would occur when exterior noise levels exceed 75 to 85 dBA.

The noise levels described above represent continuous sources. Accordingly, cumulative metrics such as the L_{eq} and DNL do not directly measure the potential effect of noise with respect to speech interference. Cumulative metrics do not provide information on the number, duration, and intensity of the individual events having the potential to disrupt communications. If speech interference is an especially critical issue, the FICON report suggests that the time above a specified noise level (TA) metric, which indicates the total time that noise exposure exceeds a specified threshold, can provide a useful "single number" indication of the potential for speech interference.

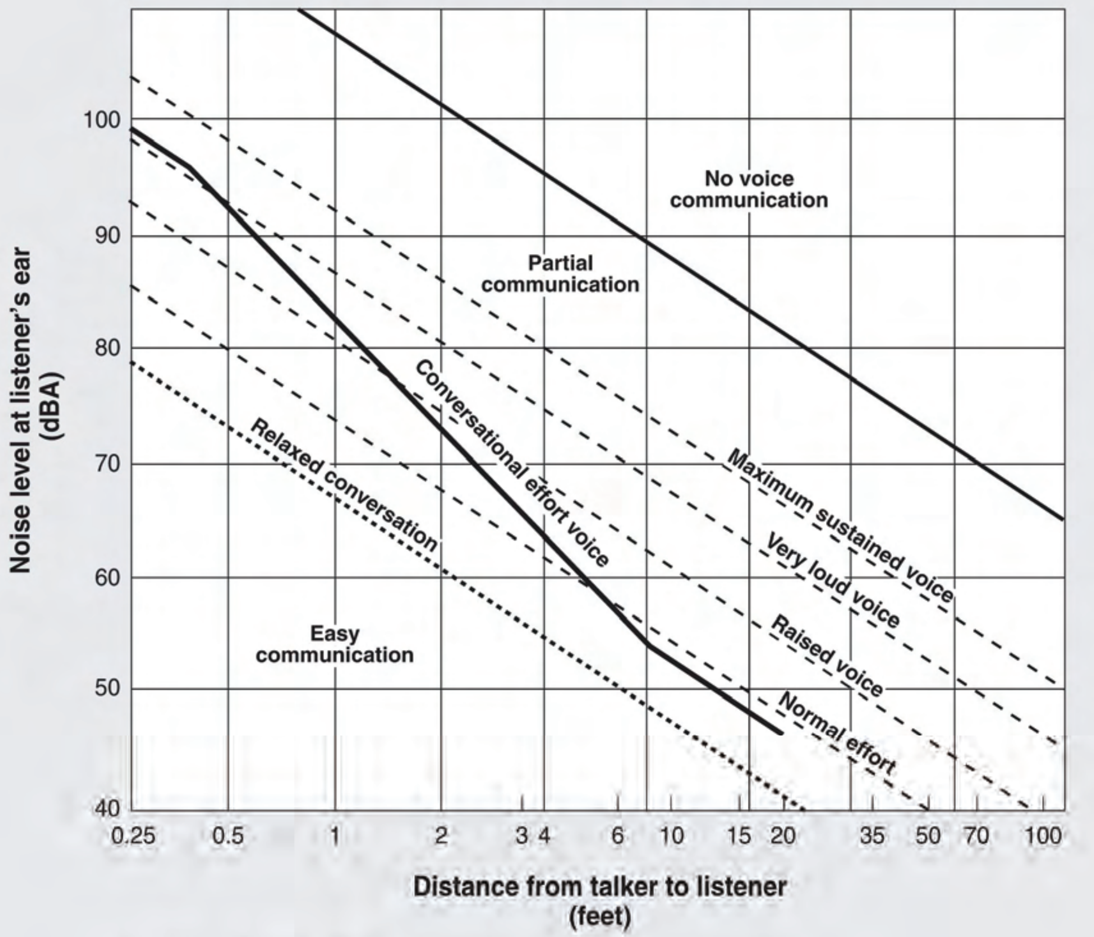
3.1.2 Sleep Disturbance

Sleep disturbance is recognized to be a major consideration in community annoyance. To some extent, the 10-dBA penalty for nighttime noise events incorporated in the DNL metric reflects this concern.

Much of the available information on sleep disturbance has been developed through laboratory studies. In the laboratory setting, research indicates that sleepers do not adjust to noise disruption over time. Although they may awaken less often and have fewer conscious memories of disturbance, noise-induced shifts in sleep levels continue to occur. On the other hand, field studies indicate that noise-induced awakenings in the home are much less prevalent than in the laboratory, and that considerable caution must be exercised in interpreting any reports of sleep disturbance, especially in noisy areas.

Figure 7

SPEECH INTERFERENCE



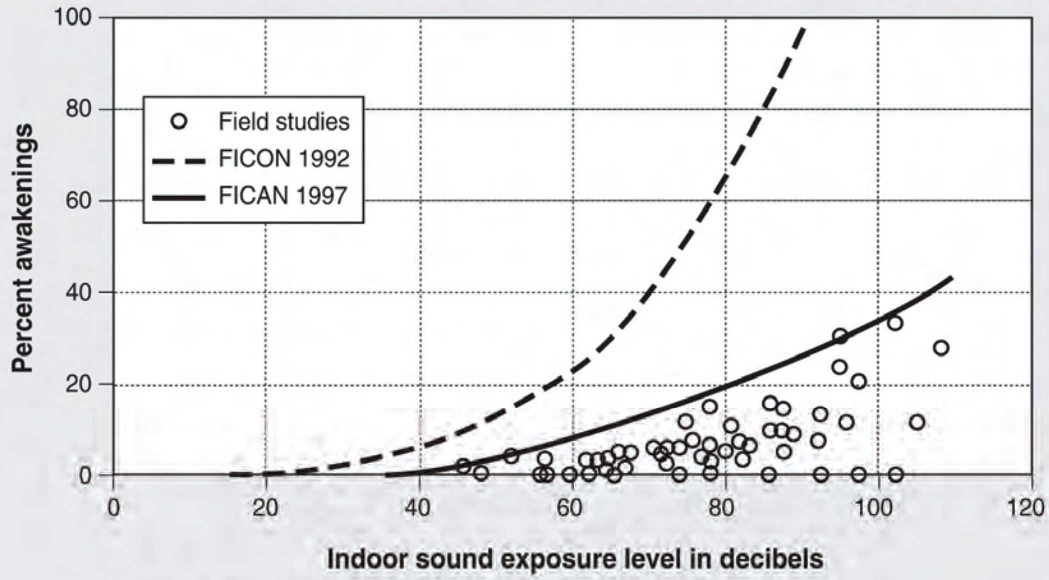
Source: U.S. EPA, 1973

3.1.3 Laboratory Studies

Laboratory research on sleep disturbance indicates that the level of noise that can cause awakenings or interfere with sleep ranges from 35 to 80 dBA, depending on the sleep stage and variability among individuals (Newman and Beattie, 1985). Figure 8 summarizes the results of laboratory studies of noise-induced awakenings. Although studies indicate that awakenings decrease as subjects become accustomed to noise, electroencephalograms show little adaptation to noise. A study conducted by K. D. Kryter suggested that noise-induced changes in sleep stage may simply be reflexive responses, reflecting normal physiological functions that are probably not a cause of stress to the individual (Kryter, 1984). EPA has identified L_{max} 35 dBA as a threshold of sleep disruption in the presence of steady noise, with a 5 percent probability awakening at an L_{max} of 40 dBA.

Figure 8

NOISE METRICS—SLEEP DISTURBANCE RESPONSE RELATIONSHIP



Source: Federal Interagency Committee on Aviation Noise, 1997.

Because people react differently in a laboratory environment, these studies provide limited insight into the potential for sleep disturbance in the home. Assessing the effect of noise on sleep disturbance is further complicated by the wide range of noise required to cause disturbance and the prevalence of sleep disruption in the absence of any noise.

3.1.4 Field Studies

A 1986 FAA report summarizes the results of eight studies conducted in homes (Fields, 1986). In all studies, sleep disturbance was correlated with cumulative noise exposure metrics such as L_{eq} and L10 (the level of sound exceeded 10 percent of the time). All studies showed increased sleep disturbance as cumulative noise exposure increased. The report also indicated that sleep disturbance was very common, even without noise events.

A 1990 review of laboratory and field studies found that noise-induced awakenings in the home were much less prevalent than in the laboratory (Persons et al., 1990). The review also found that much higher noise levels were required to induce awakenings in the home.

3.1.5 Cumulative Noise Considerations

The British Civil Aviation Authority (CAA) conducted an in-depth survey of 4,400 residents near London's Heathrow and Gatwick airports over a 4-month period in 1979.[1] This study indicated that the best correlations were found using the L_{eq} metric because some respondents could not accurately recall the time of a specific noise event with an awakening. This finding also suggests that the noise from successive overflights might increase the general state of arousal from sleep. The CAA concluded that: (1) a significant increase in

1 Directorate of Operational Research and Analysis (DORA). *Aircraft Noise and Sleep Disturbance: Final Report*. DORA Report 8008. Civil Aviation Authority, London. 1980. Cited in Kryter, 1984, p. 434.

reports of sleep arousal will occur at noise levels at or above L_{eq} 65 dB; and (2) a significant increase in the number of people reporting difficulty in getting to sleep will occur at noise levels at or above L_{eq} 70 dB.

These conclusions indicate that the DNL 65 dB contour would provide a conservative planning guideline for sleep disturbance because the DNL 65 dB contour reflecting total aircraft activity must be larger than the L_{eq} 65 dB for nighttime activity only. If only nighttime activity were considered, the DNL 65 dB contour would be the same as the L_{eq} 55 contour because of the effect of the 10 dB penalty in the DNL metric. Thus, the DNL 65 dB contour defines a noise impact envelope that encompasses the area within which significant sleep disturbance may be expected based on the CAA findings (Kryter, 1984).

3.1.6 Effects on Hearing

Hearing loss is the most significant health danger posed by noise. A 1974 study published by EPA found that continuous and prolonged exposure to noise levels of L_{eq} 70 dB or higher may result in a very small but permanent loss of hearing; that is, a noise-induced permanent threshold shift (NIPTS). Other studies have examined hearing loss among people living near airports and found that, under normal circumstances, people in the community near an airport are at no risk of suffering hearing damage from aircraft noise (Newman and Beattie, 1985).

The Occupational Safety and Health Administration (OSHA) has established standards for noise exposure in the workplace to guard against the risk of hearing loss (Table 2). OSHA standards require hearing protection when noise levels exceed 90 dBA for 8 hours per day. These regulations also require hearing conservation programs where noise levels exceed L_{eq} 85 dB for the 8-hour workday.

TABLE 2
Permissible Noise Exposures, OSHA Standards

Allowable duration (hours per day)	Sound level (dBA response)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

Source: 29 CFR Chapter XVII, Section 1910.95 (b).

Based on noise exposure studies conducted at airports in the United States, at sites with cumulative noise exposure near DNL 75 dB, the total time noise levels exceed 80 dBA typically ranges from 10 to 20 minutes, far below the critical hearing damage thresholds established by OSHA.

3.1.7 Non-auditory Health Effects

It is sometimes claimed that aircraft noise can adversely affect the physical and mental health of people living near airports. Numerous studies have examined potential effects on the cardiovascular system, mortality rates, birth weights, achievement scores, and psychiatric admissions. To date, these potential non-auditory health effects cannot be substantiated because of conflicting study findings. There is insufficient scientific evidence to support such conclusions at this time (Newman and Beattie, 1985).

3.2 Structural Damage

Aircraft noise in low-frequency ranges can cause structural vibration, such as rattling windows. Although structural vibration contributes to annoyance reported by residents near airports, aircraft noise rarely has sufficient acoustic energy to damage safely constructed structures. The National Academy of Sciences (NAS) suggested that one may conservatively consider noise levels above 130 dB lasting more than one second as potentially damaging to structures (NAS, 1977). Aircraft noise of this magnitude may occur on the ramp and runway, but would only very rarely occur beyond the property line of a commercial airport.

The risk of structural damage from aircraft noise was studied extensively as part of the environmental assessment of the Concorde supersonic jet aircraft. The probability of damage from Concorde overflights was found to be extremely slight. Actual overflight noise from the Concorde at Sully Plantation, a colonial-era structure near Washington Dulles International Airport in Fairfax County, Virginia, was recorded at 115 dBA. No damage to the historic structures in the area was found, despite their age. Because the Concorde causes significantly more vibration than conventional commercial jet aircraft, the risk of structural damage caused by aircraft noise near airports is considered to be negligible (Hershey et al., 1985).

4. Integrated Noise Model

The Integrated Noise Model (INM) is the primary method for calculating the level of aircraft noise at and around airports. The INM is a computer model using a database of aircraft noise characteristics to predict DNL based on user input on the types and number of aircraft operations, annual average airport operating conditions, average aircraft performance, and aircraft flight patterns. Consistent with the DNL metric, the primary use of the INM is to produce estimates of annual average noise conditions in the airport environs. The current version of the INM at the start of this study was Version 7.0.

4.1 INM Database

The INM aircraft database includes information for commercial, general aviation, and military aircraft powered by turbojet, turbofan, or propeller-driven engines. For each aircraft in the database, the following information is provided: (1) a set of departure profiles for each applicable trip length, (2) a set of approach parameters, and (3) SEL versus distance curves for several thrust settings. As described above, SEL is essentially an A-weighted sound level corrected for time-duration effects. Thus, the SEL represents the total noise exposure for each individual aircraft event.

4.2 Noise Contours

The noise contours derived from the INM are noise-based contours, or lines of equal noise exposure expressed in terms of DNL. These noise contours are analogous to topographic contour maps in that a set of concentric contours representing successively lower levels of DNL extend outward from the airport's runways. In accordance with FAR Part 150, each contour interval represents a DNL 5 dB decrease in annual average noise levels. FAR Part 150 requires that values of DNL 65, 70, 75 dB (and above, if applicable) be presented. Consistent with the recommendations of FICON, the DNL 60 dB contour is sometimes also presented to provide additional information on community noise exposure. Noise contour maps typically present the DNL 60, 65, 70, and 75 dB contours.

4.3 Grid Points

The INM also provides another method of showing noise levels in the airport environs. DNL or other metrics supported by the INM can be calculated for any "grid point" and presented in a number of formats. The grid point analysis is especially helpful in determining changes in noise levels resulting from some action. For example, significant noise changes, defined as a DNL 1.5 dB increase at or above DNL 65 dB in a noise-sensitive area, can be more easily presented by calculating the difference of grid points than through comparison of noise contours. Accordingly, a "differences map" showing the changes in noise levels calculated by subtracting noise exposure levels for one alternative from the noise exposure levels for a second alternative can provide a more useful picture of the effects of noise abatement alternatives. As noted in Section 2.1, there are several differences that may be of interest:

- Changes of DNL 1.5 dB at or above DNL 65 dB
- Changes of DNL 3 dB between DNL 60 and 65 dB
- Changes of DNL 5 dB at or above ambient noise levels and within the limits of acceptable modeling accuracy

In addition to DNL, grid points can be used to report all of the metrics supported by the INM. Typical grid point reports include the L_{max}, peak SELs, and TA. The INM can also produce a "detailed" grid point report that identifies the most significant aircraft operations in terms of contribution to total noise exposure at any designated point. Such reports are especially helpful in focusing on the most significant noise problems during the identification of potential noise abatement techniques.

4.4 Limitations of Noise Modeling

The validity and accuracy of noise modeling depend on the basic information used in the calculations. For future airport activities, the reliability of calculations is affected by a number of uncertainties:

- Aviation activity levels—e.g., the forecast number of aircraft operations, the types of aircraft serving the airport, the times of operation (daytime, evening, and nighttime), and aircraft flight tracks—are estimates. The achievement of the estimated levels of activity cannot be assured.
- Aircraft acoustical and performance characteristics are also estimates. When new aircraft designs are involved, aircraft noise data and flight characteristics must be estimated.
- The DNL and related metrics represent typical human response to aircraft noise. Because people vary in their responses to noise, the DNL scale can show only an average response to aircraft noise that might be expected from a community, but cannot predict an individual's reaction.
- Nominal flight tracks with dispersion are used in computer modeling to represent a wider band of actual flight tracks.

The above considerations result in more reliable noise contours for existing conditions than those projected for future conditions. Also, noise contours are more reliable closer to an airport. As the distance from the airport increases, the potential for aircraft to deviate significantly from the assumed profiles and flight tracks also increases. Accordingly, noise exposure mapping is best used for comparative purposes rather than for providing absolute values. That is, calculations provide valid comparisons between different projected conditions as long as consistent assumptions are used for all calculations. Thus, sets of DNL calculations can show (1) which of a series of potential situations would be better, and generally how much better, from the standpoint of noise exposure, or (2) anticipated changes in aircraft noise exposure over time.

Another important consideration is that a line drawn on a map does not imply that a particular noise condition exists on one side of that line and not on the other. DNL calculations are merely a means for comparing noise effects, not for precisely defining them relative to specific parcels of land. Nevertheless, DNL contours can be used to (1) highlight an existing or potential aircraft noise problem that requires attention, (2) assist in the preparation of noise compatibility programs, and (3) provide guidance in the development of land use controls, such as zoning ordinances, subdivision regulations, and building codes. DNL is considered to be the best methodology available for depicting aircraft noise exposure.

5. References

California Department of Transportation.1998. Caltrans Technical Noise Supplement. October 1998. Available online at: http://www.dot.ca.gov/hq/env/noise/pub/tens_complete.pdf.

Chantlett, E. T. 1973. *Environmental Protection.* McGraw-Hill Book Co. New York.

National Academy of Sciences (NAS). 1977. *Guidelines for Preparing Environmental Impact Statements on Noise*. Committee on Hearing, Bioacoustics, and Biomechanics. Report of Working Group.

Directorate of Operational Research and Analysis (DORA). 1980. *Aircraft Noise and Sleep Disturbance: Final Report.* DORA Report 8008. Civil Aviation Authority, London. 1980. Cited in Kryter, 1984.

Environmental Protection Agency (EPA). 1974. *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety*.

Federal Aviation Administration (FAA). 1999. Air Traffic *Noise Screening (ATNS) Model 2.0 User Manual.* January 1999.

Federal Aviation Administration (FAA). 1984. Federal Aviation Regulations Part 150. Appendix A.

Federal Aviation Administration (FAA). 1985. Federal Aviation Regulations Part 150. Airport Noise Compatibility Planning. CFR Title 14, Chapter I, Subchapter I, Part 150, Table 1. January 1985.

Federal Aviation Administration (FAA). 2004. *FAA Order 1050.1E, Environmental Impacts: Policies and Procedures.*

FAA Offices of Environment and Energy. 1985. *Aviation Noise Effects*.

Federal Interagency Committee on Noise (FICON). 1992. *Federal Agency Review of Selected Airport Noise Analysis Issues*. August 1992.

Federal Interagency Committee on Urban Noise (FICUN). 1981. Guidelines for Considering Noise in Land Use Planning and Control. 1980.

Fields, J.M. 1986. *Cumulative Airport Noise Exposure Metrics: An Assessment of Evidence for Time-of-Day Weightings.* DOT/FAA/EE-86/10. Washington DC.

Galloway, W.J. 1970. Predicting Community Response to Noise from Laboratory Data. in *Transportation Noises: A Symposium on Acceptability Criteria.* Ann Arbor Science Publishers, Ann Arbor Michigan.

Hershey, R.L., et al. *Analysis of the Effects of Concorde Aircraft Noise on Historic Structures.* FAA-RD-75-118. July 1975. Cited in Newman and Beattie, 1985. Wiggins, J.H., The Influence of Concorde Noise on Structural Vibrations, Report No. FAA-75-1241-1, July 1975, cited in Newman and Beattie, 1985.

Kryter, K. D. 1984. *Physiological, Psychological, and Social Effects of Noise*. National Aeronautics and Space Administration Reference Publication 1115.

Newman, Stephen J. and Beattie, Kristy R. 1985. *Aviation Noise Effects*. Federal Aviation Administration Report FAA-EE-85-2. March 1985.

Pearsons, K.S., et al. 1990. *Analyses of the Predictability of Noise-Induced Sleep Disturbance.* Department of Safety, Environment and Engineer, Civil Aviation Authority (United Kingdom).

Peterson, A., and E. Gross. 1967. *Handbook of Noise Control*. General Radio Company.

Schultz, T. J. 1978. Synthesis of Social Surveys on Noise Annoyance. *Journal of the Acoustical Society of America* 64:2. August 1978.

U. S. Environmental Protection Agency (EPA). 1974. *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety.* EPA 550/9-74-004. 1974.

Exhibit 3 – MCEC Study

STUDY OF ACOUSTIC AND EMF LEVELS FROM SOLAR PHOTOVOLTAIC PROJECTS

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EXECUTIVE SUMMARY

Sound pressure level and electromagnetic field (EMF) measurements were made at three utility-scale sites with solar photovoltaic (PV) arrays with a capacity range of 1,000 to 3,500 kW (DC at STC) under a full-load condition (sunny skies and the sun at an approximate 40^{o} azimuth). Measurements were taken at set distances from the inverter pads and along the fenced boundary that encloses the PV array. Measurements were also made at set distances back from the fenced boundary. Broadband and 1/3-octave band sound levels were measured, along with the time variation of equipment sound levels.

EMF measurements were also made at one residential PV installation with a capacity of 8.6 kW under a partial-load condition. PV array operation is related to the intensity of solar insolation. Less sunshine results in lower sound and EMF levels from the equipment, and no sound or EMF is produced at night when no power is produced. A description of acoustic terms and metrics is provided in Appendix A, and EMF terms and metrics are presented in Appendix B. These appendices provide useful information for interpreting the results in this report and placing them in context, relative to other sound and EMF sources.

Sound levels along the fenced boundary of the PV arrays were generally at background levels, though a faint inverter hum could be heard at some locations. Any sound from the PV array and equipment was inaudible at set back distances of 50 to 150 feet from the boundary. Average L_{eq} sound levels at a distance of 10 feet from the inverter face varied over the range of 48 dBA to 61 dBA for Site 2 and Site 3 Inverters[1], and were higher in the range of 59 to 72 dBA for Site 1 Inverters. Along the axis perpendicular to the plane of the inverter face and at distances of 10 to 30 feet, sound levels were 4 to 13 dBA higher compared to levels at the same distance along the axis parallel to the inverter face. At 150 feet from the inverter pad, sound levels approached background levels. Sound level measurements generally followed the hemispherical wave spreading law (-6 dB per doubling of distance).

The time domain analysis reveals that 0.1-second L_{eq} sound levels at a distance of 10 feet from an inverter pad generally varied over a range of 2 to 6 dBA, and no recurring pattern in the rise and fall of the inverter sound levels with time was detected. The passage of clouds across the face of the sun caused cooling fans in the inverters to briefly turn off and sound levels to drop 4 dBA.

[1] The same make of inverters were used at Sites 2 and 3.

The 1/3-octave band frequency spectrum of inverter sound at the close distance of 10 feet shows energy peaks in several mid-frequency and high-frequency bands, depending on the inverter model. Tonal sound was found to occur in harmonic pairs: 63/125 Hz; 315/630 Hz; 3,150/6,300 Hz; and 5,000/10,000 Hz. The high frequency peaks produce the characteristic "ringing noise" or high-frequency buzz heard when one stands close to an operating inverter. The tonal sound was not, however, audible at distances of 50 to 150 feet beyond the PV array boundary, and these tonal peaks do not appear in the background sound spectrum. All low-frequency sound from the inverters below 40 Hz is inaudible, at all distances.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has a recommended electric field level exposure limit of 4,200 Volts/meter (V/m) for the general public. At the utility scale sites, electric field levels along the fenced PV array boundary, and at the locations set back 50 to 150 feet from the boundary, were not elevated above background levels (< 5 V/m). Electric fields near the inverters were also not elevated above background levels (< 5 V/m). At the residential site, indoor electric fields in the rooms closest to the roof-mounted panels and at locations near the inverters were not elevated above background levels (< 5 V/m).

The International Commission on Non-Ionizing Radiation Protection has a recommended magnetic field level exposure limit of 833 milli-Gauss (mG) for the general public. At the utility scale sites, magnetic field levels along the fenced PV array boundary were in the very low range of 0.2 to 0.4 mG. Magnetic field levels at the locations 50 to 150 feet from the fenced array boundary were not elevated above background levels (<0.2 mG). There are significant magnetic fields at locations a few feet from these utility-scale inverters, in the range of 150 to 500 mG. At a distance of 150 feet from the inverters, these fields drop back to very low levels of 0.5 mG or less, and in many cases to background levels (<0.2 mG). The variation of magnetic field with distance generally shows the field strength is proportional to the inverse cube of the distance from equipment.

At the residential site, indoor magnetic field levels in the rooms closest to the roof-mounted panels were in the low range of 0.2 to 1.4 mG. There are low-level magnetic fields at locations a few feet from the inverters, in the range of 6 to 10 mG. At a distance of no more than 9 feet from the inverters, these fields dropped back to the background level at this residential site of 0.2 mG. Due to the relatively high background level in the residential site basement where the inverters were housed, the relationship of magnetic field strength to distance from the inverters could not be discerned.

TABLE OF CONTENTS

1.0 INTRODUCTION

The goal of this study is to conduct measurements at several ground-mounted PV arrays in Massachusetts to determine the sound pressure levels and electromagnetic field (EMF) levels generated by PV arrays and the equipment pads holding inverters and small transformers. This information will be used to inform local decision-makers and the public about the acoustic and EMF levels in the vicinity of PV projects.

Measurements were made at three utility-scale sites having PV arrays with a capacity range of 1,000 to 3,500 kW (DC at STC), with weather conditions consisting of sunny skies and the sun at approximately 40^{o} azimuth. Measurements were also made at one residential[2] PV installation with a capacity of 8.6 kW under a partial-load condition. Sound level and EMF data were collected at set distances from the inverter pads and along the fenced boundary of the PV array. Measurements were also made at set distances back from the fenced boundary. Broadband and 1/3-octave band sound levels were measured, along with the time variation of equipment sound levels. Figure 1 shows a schematic map of a typical utility scale PV array containing four inverter pads and a fenced boundary. The orange stars show typical measurement locations around the fenced boundary of the array and at fixed set back distances of 50 feet, 100 feet, and 150 feet from the boundary. The green stars represent typical measurement locations at three set back distances from inverters on two of the equipment pads. At each equipment pad that was sampled, sound level measurements were made in two directions: along an axis parallel to the inverter face and along an axis perpendicular to the inverter face. Figure 2 illustrates a sound meter setup along the axis perpendicular to (90^{o} from) an inverter face.

Section 2.0 of this report describes the measurement methods and locations, while Section 3.0 presents the measurement results in detail for the four sites. Study conclusions are given in Section 4.0. A description of acoustic terms and metrics is provided in Appendix A, and EMF terms and metrics are presented in Appendix B. These appendices provide useful information for interpreting the results in this report and placing them in context, relative to other sound and EMF sources.

[2] Only EMF measurements were made at the residential site.

Figure 1. Schematic Map of Sound and EMF Measurement Locations at a Solar Photovoltaic (PV) Array

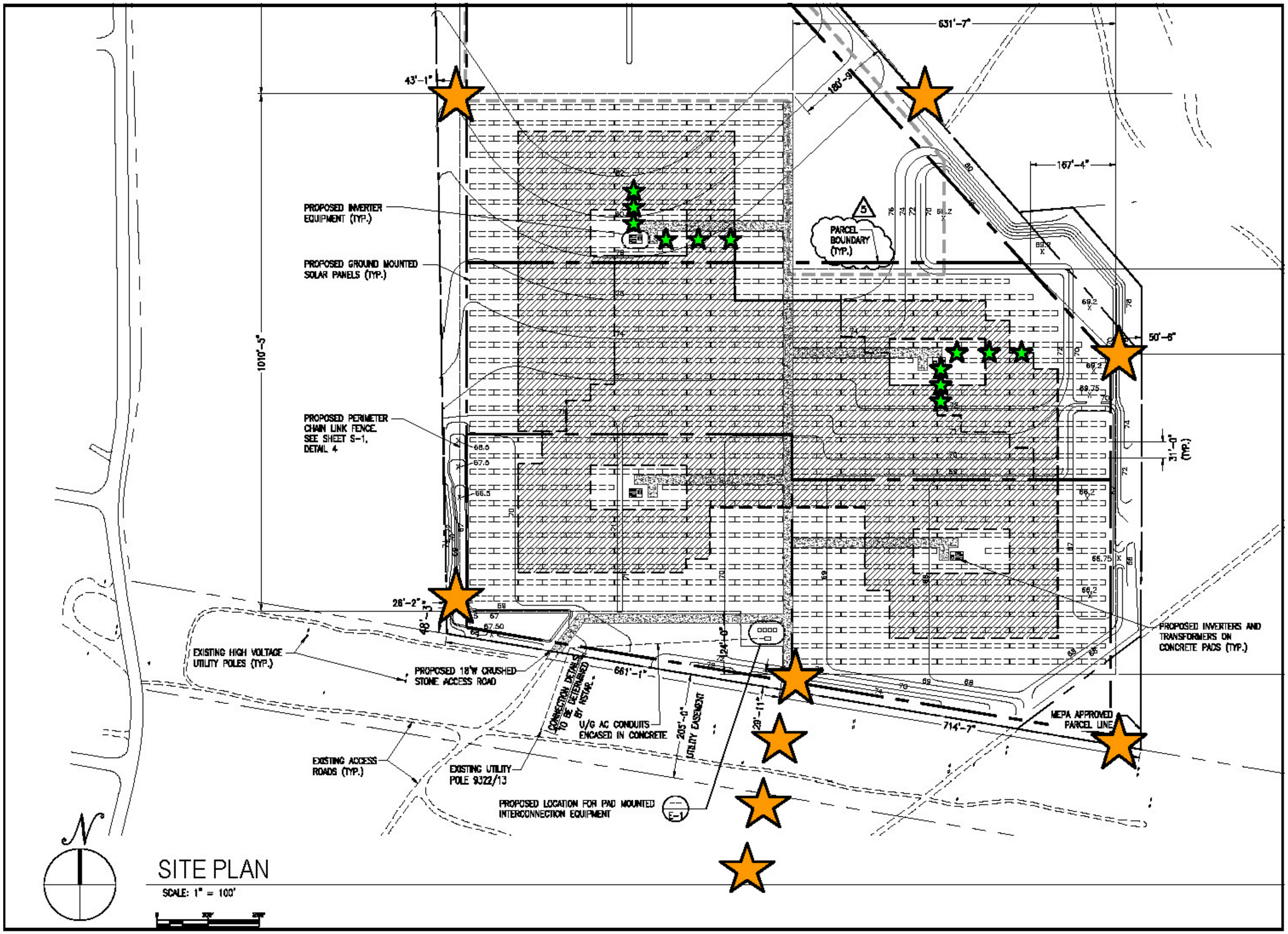


Figure 2. Sound Level Meter on the Axis Perpendicular to the Face of an Inverter at a Solar Photovoltaic (PV) Array

2.0 MEASUREMENT METHODS AND LOCATIONS

Sound pressure and EMF levels were measured along the fenced boundary of each PV array, at three set back distances from the boundary, and at fixed distances from equipment pads housing inverters and transformers (see Figures 1 and 2). Sound levels were measured with a tripod-mounted ANSI Type 1 sound meter, a Bruel & Kjaer Model 2250 meter, equipped with a large 7-inch ACO-Pacific WS7-80T 175 mm (7-inch) wind screen that is oversize and specially designed to screen out wind flow noise. An experimental study of wind-induced noise and windscreen attenuation effects by Hessler[3] found that the WS7-80T windscreen keeps wind-induced noise at the infrasound frequency band of 16 Hz to no more than 42 dB for moderate across-the–microphone wind speeds. That minimal level of wind-induced noise is 8 to 20 dB below the 16-Hz levels measured in this study.

The B&K Model 2250 measures 1/3-octave bands down to 6.3 Hz, well into the infrasonic range, and up to 20,000 Hz, the upper threshold of human hearing. The sound meter first recorded short-term (1-minute L_{eq} and L_{90}) broadband sound levels (in A-weighted decibels, dBA) at the established survey points. Then the sound meter was placed at the nearest measurement distance to each equipment pad to record a 10-minute time series of broadband and 1/3-octave band L_{eq} sound levels (in decibels, dB) at 0.1-second intervals. The L_{90} sound level removes intermittent noise and thus is lower than the L_{eq} sound level in the tables of results provided in Section 3.

EMF levels of both the magnetic field (in milliGauss, mG) and the electric field (in Volts/meter, V/m) were measured using a pair of Trifield Model 100XE EMF Meters. These instruments perform three-axis sampling simultaneously, enabling rapid survey of an area. The Trifield meters have a range for magnetic fields of 0.2 to 10,000 mG, and for electric fields from 5 to 1,000 V/m. EMF measurements were taken at the same survey points as the sound level measurements.

Measurements were made along the fenced boundary around each PV array at four to six evenly-spaced locations (depending on the size of the array), and at three additional locations set back 50 feet, 100 feet, and 150 feet from the boundary. At each equipment pad that was sampled, sound level

[3] Hessler, G., Hessler, D., Brandstatt, P., and Bay, K., "Experimental study to determine wind-induced noise and windscreen attenuation effects on microphone response for environmental wind turbine and other applications", Noise Control Eng. J., 56(4), 2008.

measurements were made in two directions: parallel to the inverter face, and perpendicular to the equipment face. The closest sound monitoring location was selected at a distance "1X" where the inverter or transformer sound was clearly audible above background levels. The closest EMF monitoring location was selected at a distance "1X" where magnetic field levels were approximately 500 mG, a level that is below the ICNIRP-recommended[4] human exposure limit of 833 mG (see Appendix B). Additional sampling points were then placed at distances[5] of 2X, 3X, and at 150 feet from the equipment pad, in the two orthogonal directions. There were a total of eight monitoring locations for each equipment pad, and seven to nine locations for the PV array boundary.

Measurements were made on October 11, 17, 22 and 26, 2012 around 12:30 p.m. EDT, the time of peak solar azimuth, and only on days for which clear skies were forecast to maximize solar insolation to the PV array. The peak solar azimuth in southern Massachusetts was approximately 40^{o} azimuth on these dates. Consistent with standard industry practice, background levels of sound and EMF were measured at representative sites outside the fenced boundary of the PV array and far enough away to not be influenced by it or any other significant nearby source. The background levels presented for each site were made at distances of 50 feet, 100 feet, and 150 feet from the fenced boundary around the PV array (see Figure 1).

[4] International Commission on Non-Ionizing Radiation Protection.

[5] Location 2X is twice the distance from the equipment as location 1X; Location 3X is three times that distance.

3.0 MEASUREMENT RESULTS

Sound and EMF measurements were made at the following four PV arrays, presented in the following sections:

Site 1 – Achusnet ADM, Wareham, MA
Site 2 – Southborough Solar, Southborough, MA
Site 3 – Norfolk Solar, Norfolk, MA
Site 4 – Residential PV array owned by Massachusetts Audubon Society, Sharon, MA

3.1 Site 1 – Achusnet ADM

Facility Location:	27 Charlotte Furnace Road, Wareham, MA
Facility Owner:	Borrego Solar Systems, Inc.
System Capacity:	3,500 kW
Power Output During Monitoring:	3,500 kW
No. & Size Inverters:	(7) 500-kW inverters
Date Measured:	Thursday October 11, 2012
Cloud Cover:	0%
Winds:	West 10-12 mph
Ground:	Open area between cranberry bogs, no buildings or vegetation.
Background Sound:	Mean value L_{eq} of 46.4 dBA (range of 45.6 to 47.0 dBA). Mean value of L_{90} 43.9 dBA (range of 41.6 to 45.4 dBA). Sources included highway traffic on I-495 (to the south), earthmoving equipment to the east, birds and other natural sounds.
Background EMF:	None (< 0.2 mG and < 5 V/m) except along southern boundary from hi-voltage power lines overhead, and near the eastern boundary from low-voltage power lines overhead.

The solar photovoltaic array is in a flat area between cranberry bogs east of Charlotte Furnace Road in Wareham and the boundary of the array is fenced. The surrounding area has no buildings or vegetation. There are four equipment pads within the PV array, each housing one or two inverters. Measurements were made at two equipment pads: 1) the Northwest Pad, which contains two inverters and a small transformer, and 2) the Northeast Pad, which has one inverter and a small transformer. The sound and EMF measurements made at Site 1 are summarized in Tables 1 through 3. Figures 3 and 4 present a time series graph of 0.1-second L_{eq} sound levels at the nearest measurement location

(1X) for the Northwest and Northeast Equipment Pads, while Figure 5 provides the corresponding 1/3-octave band spectra for the sound level measurements at those same locations along with the spectrum for background sound levels.

Sound Levels

Background sound levels varied over time and space across the site. Highway traffic noise was the primary background sound source and higher levels were measured for locations on the south side of the site closer to the highway. Variable background sound was also produced by trucking activity to the east of the PV array, where sand excavated during the PV array's construction and stored in large piles was being loaded with heavy equipment into dump trucks and hauled away. Background sound levels varied over a range of 6 dBA. Background mean value L_{eq} and L_{90} levels were 46.4 dBA and 43.9 dBA, respectively. The PV array was inaudible outside of the fenced boundary, and was also inaudible everywhere along the boundary except at the North East boundary location where a faint inverter hum could be heard. Broadband sound levels at the locations set back 50 to 150 feet from the boundary are not elevated above background levels.

L_{eq} sound levels at a distance of 10 feet from the inverter face on the North West Pad (which holds two 500-kW inverters) were 68.6 to 72.7 dBA and at the same distance from the North East Pad (which holds only one 500-kW inverter) were lower at 59.8 to 66.0 dBA. Along the axis perpendicular to the inverter face measured sound levels were 4 to 6 dBA higher than at the same distance along the axis parallel to the inverter face. The sound levels generally declined with distance following the hemispherical wave spreading law (approximately -6 dB per doubling of distance) and at a distance of 150 feet all inverter sounds approached background sound levels. Due to the layout of the solar panels, the measurements made perpendicular to the inverter face and at a distance of 150 feet were blocked from a clear line of sight to the inverter pad by many rows of solar panels, which acted as sound barriers.

The time domain analysis presented in Figures 3 and 4 reveal that 0.1-second L_{eq} sound levels at the close distance of 10 feet generally varied 3 to 4 dBA at the North West Pad and 2 to 3 dBA at the North East Pad. The graphs show no recurring pattern in the rise and fall of the inverter sound levels over the measurement period of ten minutes. The inverters registered full 500-kW capacity during both 10-minute monitoring periods.

The frequency spectrum of equipment sound at the close distance of 10 feet (Figure 5) shows energy peaks in four 1/3-octave bands, which are most pronounced for the North West Pad: 315 Hz, 630 Hz, 3,150 Hz, and 6,300 Hz. The two higher frequency peaks produce the characteristic "ringing noise" or high-frequency buzz heard when one stands close to an operating inverter. The second frequency peak in each pair is a first-harmonic tone (6,300 Hz being twice the frequency of 3,150 Hz). The tonal sound exhibited by Figure 5 is not, however, audible at distances of 50 to 150 feet beyond the PV array boundary, and these tonal peaks do not appear in the background sound spectrum shown in Figure 5. The dashed line in Figure 5 is the ISO 226 hearing threshold and it reveals that low-frequency sound from the inverters below 40 Hz is inaudible, even at a close distance. The background sound spectrum is smooth except for a broad peak around 800 Hz caused by distant highway traffic noise and a peak at 8,000 Hz that represents song birds.

Electric Fields

Electric field levels along the PV array boundary, and at the locations set back 50 to 150 feet from the boundary, are not elevated above background levels (< 5 V/m). The one measurement at 5.0 V/m in Table 1 was caused by the field around a nearby low-voltage power line overhead. Electric fields near the inverters are also not elevated above background levels (< 5 V/m). The one measurement at 10.0 V/m in Table 3 was caused by the meter being close to the front face of a solar panel at the 150-foot set back distance.

Magnetic Fields

Magnetic field levels along the PV array boundary and 50 feet from the boundary were in the very low range of 0.2 to 0.3 mG, except at the southern end of the boundary that is close to overhead high-voltage power lines, owned by the local utility and not connected to the project, where levels of 0.7 to 3 mG were measured, caused by those hi-voltage power lines. Magnetic field levels at the location 100 feet from the boundary were elevated by a low-voltage power line overhead. At 150 feet from the boundary, the magnetic field is not elevated above background levels (<0.2 mG).

Table 3 reveals that there are significant magnetic fields at locations a few feet from inverters, around 500 mG. These levels drop back to 0.2 to 0.5 mG at distances of 150 feet from the inverters. The variation of magnetic field with distance shown in Table 3 generally shows the field strength is proportional to the inverse cube of the distance from equipment. Following that law, the magnetic field at 5 feet of 500 mG should decline to 0.02 mG (< 0.2 mG) at 150 feet. The measured levels of 0.1 to 0.5 mG at 150 feet listed in Table 3 are likely caused by small-scale magnetic fields setup around the PV cells and connecting cables near the sampling locations.

TABLE 1

SOUND AND EMF LEVELS MEASURED AT SITE 1
PV ARRAY BOUNDARY

Boundary Location	L_{90} Level (dBA)	L_{eq} Level (dBA)	Magnetic Field (mG)	Electric Field (V/m)
North West Boundary	39.1	42.5	< 0.2	< 5
South West Boundary	43.6	44.7	1.8	< 5
South Center Boundary	44.8	48.1	3.0	< 5
South East Boundary	44.0	45.6	0.7	< 5
North East Boundary	42.2	43.9	< 0.2	< 5
North Center Boundary	43.4	44.3	0.3	< 5
Background Mean Values	43.9	46.4	< 0.2	< 5
Set back 50 feet from Boundary	41.6	47.0	0.2	< 5
Set back 100 feet from Boundary	45.4	46.7	0.4	5.0
Set back 150 feet from Boundary	44.7	45.6	< 0.2	< 5

TABLE 2

SOUND LEVELS MEASURED AT SITE 1
EQUIPMENT PADS

Equipment Pad / Direction / Distance	L_{90} Level (dBA)	L_{eq} Level (dBA)
North West Pad / Parallel to Inverter Face / 10 feet	67.6	68.6
North West Pad / Parallel to Inverter Face / 20 feet	61.8	63.1
North West Pad / Parallel to Inverter Face / 30 feet	58.8	60.6
North West Pad / Parallel to Inverter Face / 150 feet	45.2	46.0
North West Pad / Perpendicular to Inverter Face / 10 feet	71.8	72.7
North West Pad / Perpendicular to Inverter Face / 20 feet	63.5	64.8
North West Pad / Perpendicular to Inverter Face / 30 feet	59.5	62.3
North West Pad / Perpendicular to Inverter Face / 150 feet	41.8	43.0
North East Pad / Parallel to Inverter Face / 10 feet	59.1	59.8
North East Pad / Parallel to Inverter Face / 20 feet	55.4	56.2
North East Pad / Parallel to Inverter Face / 30 feet	54.8	55.7
North East Pad / Parallel to Inverter Face / 150 feet	43.4	44.0
North East Pad / Perpendicular to Inverter Face / 10 feet	65.5	66.0
North East Pad / Perpendicular to Inverter Face / 20 feet	59.8	60.2
North East Pad / Perpendicular to Inverter Face / 30 feet	56.3	56.9
North East Pad / Perpendicular to Inverter Face / 150 feet	41.0	43.6

TABLE 3

EMF LEVELS MEASURED AT SITE 1
EQUIPMENT PADS

Equipment Pad / Direction / Distance	Magnetic Field (mG)	Electric Field (V/m)
North West Pad / Parallel to Inverter Face / 5 feet 3 inches	500	< 5
North West Pad / Parallel to Inverter Face / 10 feet 6 inches	10.5	< 5
North West Pad / Parallel to Inverter Face / 15 feet 9 inches	2.75	< 5
North West Pad / Parallel to Inverter Face / 150 feet	0.2	< 5
North West Pad / Perpendicular to Inverter Face / 4 feet	500	< 5
North West Pad / Perpendicular to Inverter Face / 8 feet	200	< 5
North West Pad / Perpendicular to Inverter Face / 12 feet	6.5	< 5
North West Pad / Perpendicular to Inverter Face / 150 feet	0.5	< 5
North East Pad / Parallel to Inverter Face / 3 feet 10 inches	500	< 5
North East Pad / Parallel to Inverter Face / 7 feet 8 inches	30	< 5
North East Pad / Parallel to Inverter Face / 11 feet 10 inches	4.5	< 5
North East Pad / Parallel to Inverter Face / 150 feet	0.2	10.0
North East Pad / Perpendicular to Inverter Face / 7 feet 6 inches	500	< 5
North East Pad / Perpendicular to Inverter Face / 15 feet	10	< 5
North East Pad / Perpendicular to Inverter Face / 22 feet 6 inches	2.1	< 5
North East Pad / Perpendicular to Inverter Face / 150 feet	0.1	< 5

Figure 3. Time Variation of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pads for Site #1

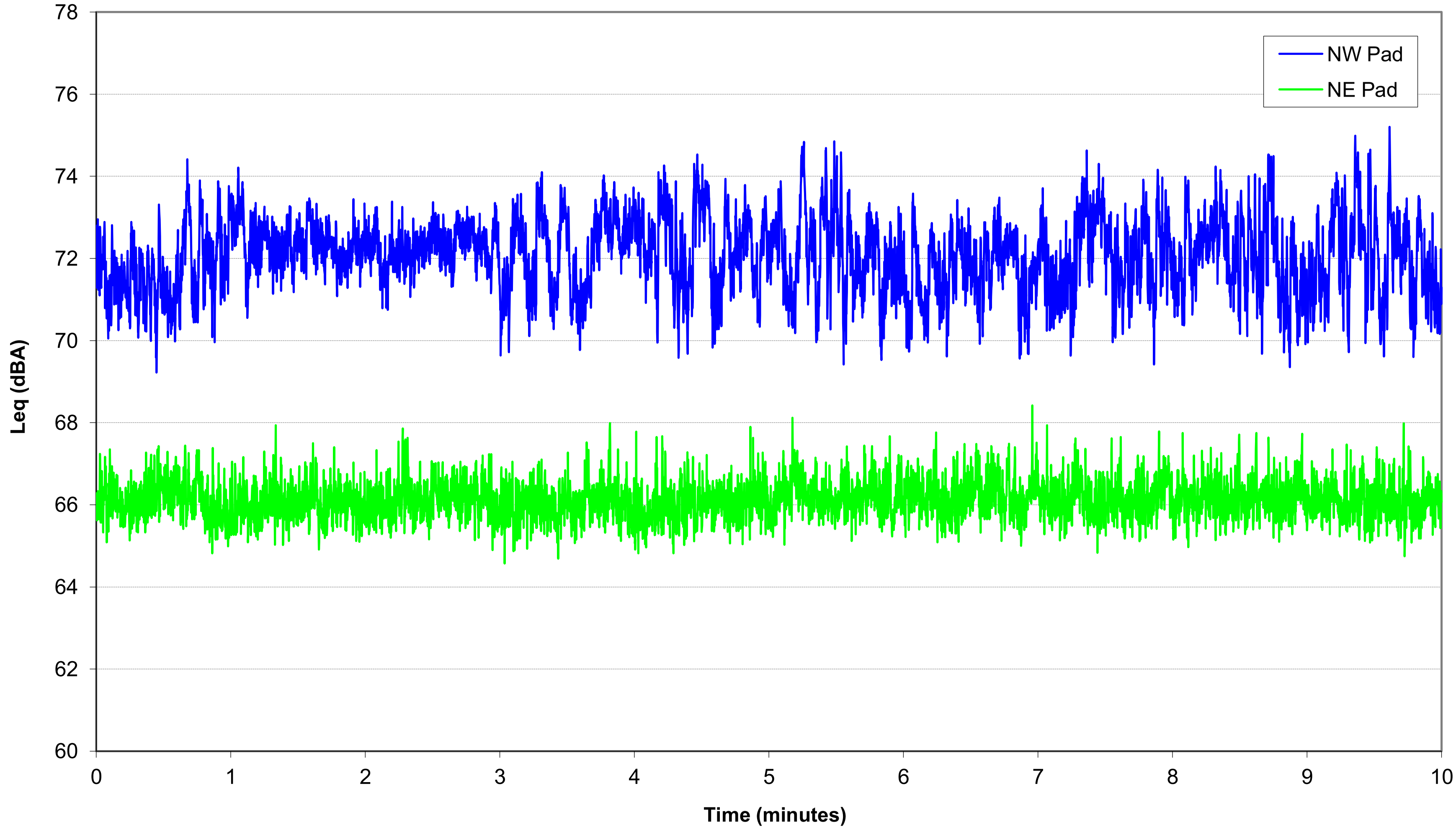


Figure 4. Time Variation of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pads for Site #1 - First 10 Seconds of Measurements

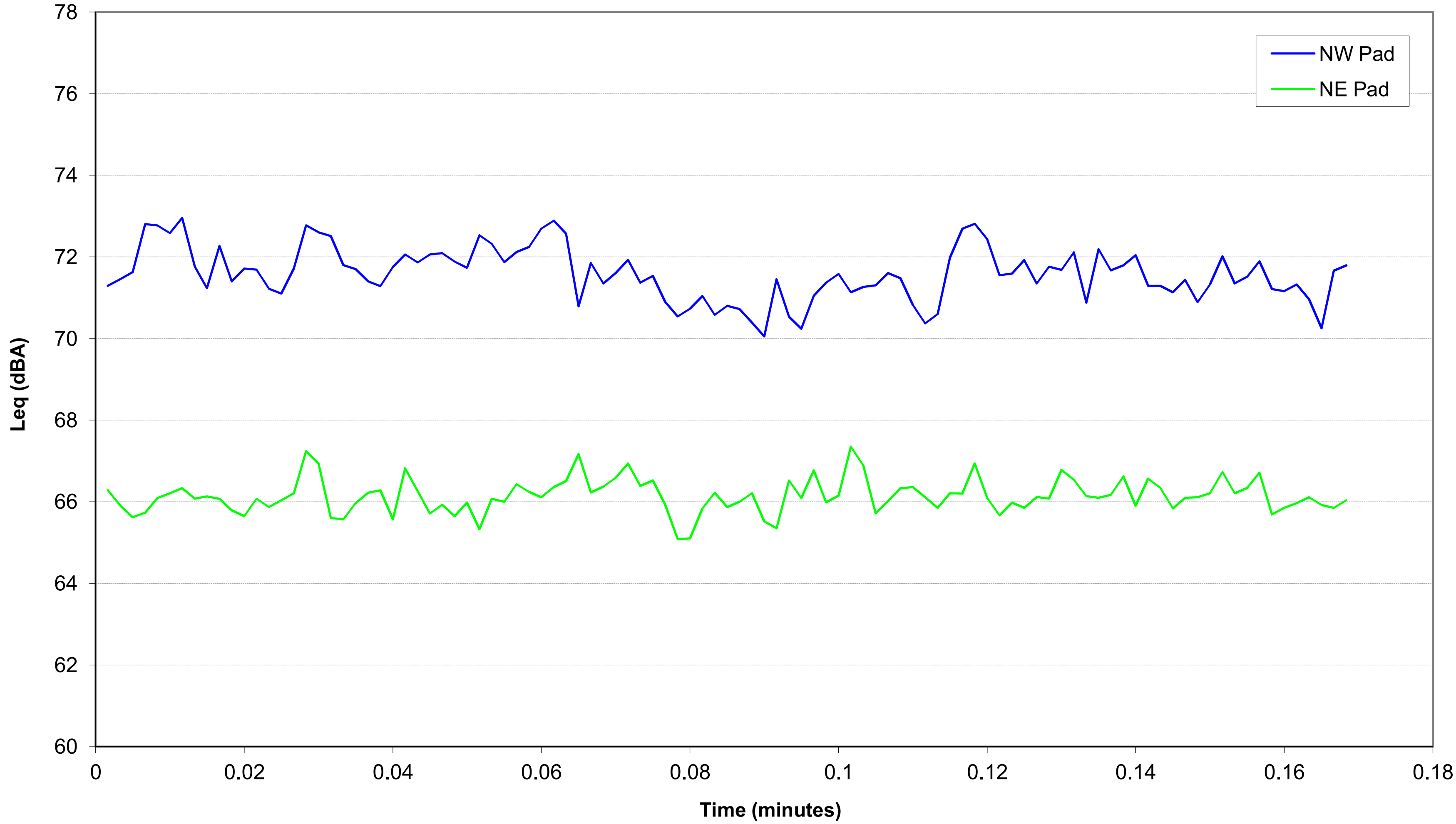
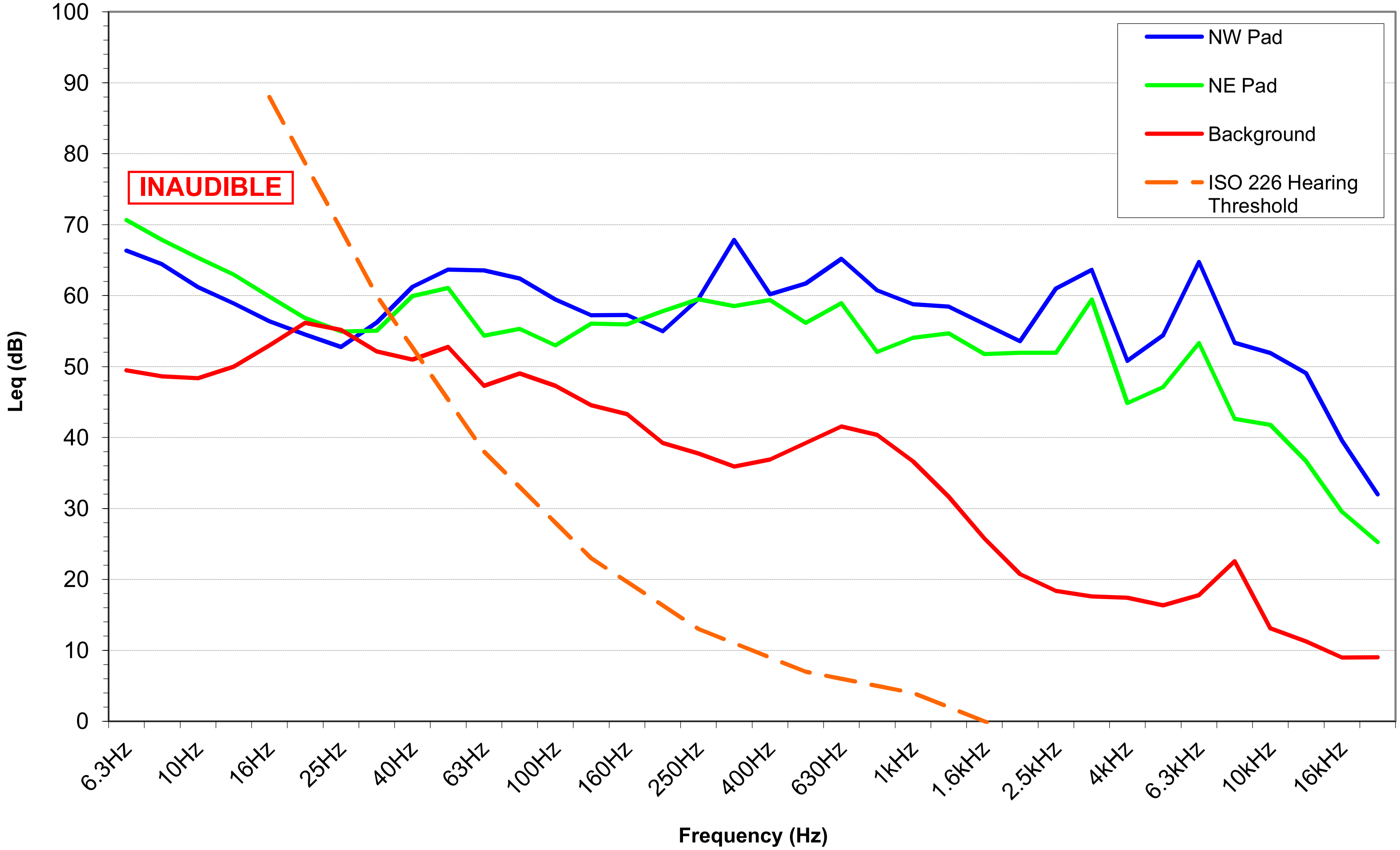


Figure 5. Frequency Spectrum of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pads for Site #1



3.2 Site 2 – Southborough Solar

Facility Location:	146 Cordaville Road, Southborough, MA
Facility Owner:	Southborough Solar, LLC
System Capacity:	1,000 kW
Power Output During Monitoring:	1,000 kW
No. & Size Inverters:	(2) 500-kW inverters
Date Measured:	Wednesday October 17, 2012
Cloud Cover:	5% (high, thin cirrus)
Winds:	Northwest 3-5 mph
Ground:	Wooded areas and wetlands surround the PV array, and a building is located to the south where the inverters are housed.
Background Sound:	Mean value L_{eq} of 53.1 dBA (range of 51.0 to 55.9 dBA). Mean value L_{90} of 49.6 dBA (range of 48.6 to 50.3 dBA). Sources included roadway traffic on Cordaville Road (to the west) and Route 9 (to the north) and natural sounds.
Background EMF:	None (< 0.2 mG and < 5 V/m).

The solar photovoltaic array is in a cleared area of land east of Cordaville Road in Southborough and the boundary of the array is fenced. The array is surrounded by wetlands and woods. The two inverters are not within the PV array; instead they are located on a single pad at the southeast corner of the building that lies south of the PV array. Measurements were made at the one equipment pad housing the two inverters. Due to the close proximity of wetlands to the fenced boundary for the PV array, it was not possible to obtain measurements 50 to 150 feet from the boundary. Instead, measurements were taken 50 to 150 feet set back from the property boundary of the site near where the inverter pad is located. The sound and EMF measurements made at Site 2 are summarized in Tables 4 through 6. Figures 6 and 7 present a time series graph of 0.1-second L_{eq} sound levels at the nearest measurement location (1X) for the equipment pad, while Figure 8 provides the corresponding 1/3-octave band spectra for the sound level measurements at those same locations along with the spectrum for background sound levels.

<u>Sound Levels</u>

Background sound levels varied over time and space across the site, depending on the distance from Cordaville Road, which carries heavy traffic volumes. Roadway traffic noise was the primary background sound source and higher levels were measured for locations on the west side of the site closer to Cordaville Road. Background sound levels varied over a range of 5 to 7 dBA. The background mean value L_{eq} and L_{90} levels were 53.1 dBA and 49.6 dBA, respectively. The inverters were inaudible at a distance of 50 feet outside of the site boundary. Broadband sound levels at the locations set back 50 to 150 feet from the boundary are not elevated above background levels.

L_{eq} sound levels at a distance of 10 feet from the inverter face on the equipment pad (which holds two 500-kW inverters) were 48.1 to 60.8 dBA. Along the axis perpendicular to the inverter face, measured sound levels were 10 to 13 dBA higher than at the same distance along the axis parallel to the inverter face. The sound levels did not follow the expected hemispherical wave spreading law (approximately -6 dB per doubling of distance) and declined at a lower rate with increasing distance due to the relatively high background sound levels from nearby roadway traffic. At a distance of 150 feet, all inverter sounds were below background sound levels.

The time domain analysis presented in Figures 6 and 7 reveal that 0.1-second L_{eq} sound levels at the close distance of 10 feet generally varied 5 to 6 dBA. The graphs show no recurring pattern in the rise and fall of the inverter sound levels over the measurement period of ten minutes. The rise and fall in inverter sound levels over several minutes is thought to be due to the passage of sheets of high thin cirrus clouds across the face of the sun during the measurements. The inverters registered full 500-kW capacity during both 10-minute monitoring periods.

The frequency spectrum of equipment sound at the close distance of 10 feet (Figure 8) shows energy peaks in two 1/3-octave bands: 5,000 and 10,000 Hz. These high frequency peaks produce the characteristic “ringing noise” or high-frequency buzz heard when one stands close to an operating inverter. The second frequency peak is a first-harmonic tone (10 kHz being twice the frequency of 5 kHz). The tonal sound exhibited by Figure 8 is not, however, audible at distances of 50 to 150 feet beyond the site boundary, and these tonal peaks do not appear in the background sound spectrum shown in Figure 8. The dashed line in Figure 8 is the ISO 226 hearing threshold and it reveals that low-frequency sound from the inverters below 40 Hz is inaudible, even at a close distance. The background sound spectrum declines smoothly with increasing frequency in the audible range except for a rise around 800 to 2,000 Hz caused by nearby roadway traffic noise.

Electric Fields

Electric field levels along the PV array boundary, and at the locations set back 50 to 150 feet from the site boundary, are not elevated above background levels (< 5 V/m).

Magnetic Fields

Magnetic field levels along the PV array boundary were in the very low range of 0.2 to 0.4 mG. Magnetic field levels at the locations 50 to 150 feet from the site boundary were not elevated above background levels (<0.2 mG).

Table 6 reveals that there are significant magnetic fields at locations a few feet from inverters, in the range of 200 to 500 mG. These levels drop back to background levels (<0.2 mG) at distances of 95 to 150 feet from the inverters. The variation of magnetic field with distance shown in Table 6 generally shows the field strength is proportional to the inverse cube of the distance from equipment.

TABLE 4

SOUND AND EMF LEVELS MEASURED AT SITE 2
PV ARRAY BOUNDARY

Boundary Location	L_{90} Level (dBA)	L_{eq} Level (dBA)	Magnetic Field (mG)	Electric Field (V/m)
North West Boundary	53.3	54.4	0.2	< 5
South West Boundary	52.4	54.4	0.2	< 5
South East Boundary	48.3	50.8	0.4	< 5
North East Boundary	46.8	49.8	< 0.2	< 5
Background Mean Values	49.6	53.1	< 0.2	< 5
Set back 50 feet from Boundary	50.3	52.3	< 0.2	< 5
Set back 100 feet from Boundary	49.9	55.9	< 0.2	< 5
Set back 150 feet from Boundary	48.6	51.0	< 0.2	< 5

TABLE 5

**SOUND LEVELS MEASURED AT SITE 2
EQUIPMENT PAD**

Equipment Pad / Direction / Distance	L_{90} Level (dBA)	L_{eq} Level (dBA)
Parallel to Inverter Face / 10 feet	46.7	48.1
Parallel to Inverter Face / 20 feet	44.8	46.2
Parallel to Inverter Face / 30 feet	44.3	45.6
Parallel to Inverter Face / 95 feet*	44.0	45.6
Perpendicular to Inverter Face / 10 feet	59.9	60.8
Perpendicular to Inverter Face / 20 feet	57.3	58.7
Perpendicular to Inverter Face / 30 feet	53.4	54.5
Perpendicular to Inverter Face / 150 feet	46.2	47.5

*Measurements could not be taken at 150 feet parallel to inverter face because of the close proximity of wetlands. Instead, a measurement was made at the farthest practical distance in that direction at 95 feet.

TABLE 6

**EMF LEVELS MEASURED AT SITE 2
EQUIPMENT PAD**

Equipment Pad / Direction / Distance	Magnetic Field (mG)	Electric Field (V/m)
Parallel to Inverter Face / 4 feet	200	< 5
Parallel to Inverter Face / 8 feet	10	< 5
Parallel to Inverter Face / 12 feet	0.8	< 5
Parallel to Inverter Face / 95 feet*	<0.2	< 5
Perpendicular to Inverter Face / 4 feet	500	< 5
Perpendicular to Inverter Face / 8 feet	25	< 5
Perpendicular to Inverter Face / 12 feet	4.5	< 5
Perpendicular to Inverter Face / 150 feet	<0.2	< 5

*Measurements could not be taken at 150 feet parallel to inverter face because of the close proximity of wetlands. Instead, a measurement was made at the farthest practical distance in that direction at 95 feet.

Figure 6. Time Variation of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pad for Site #2

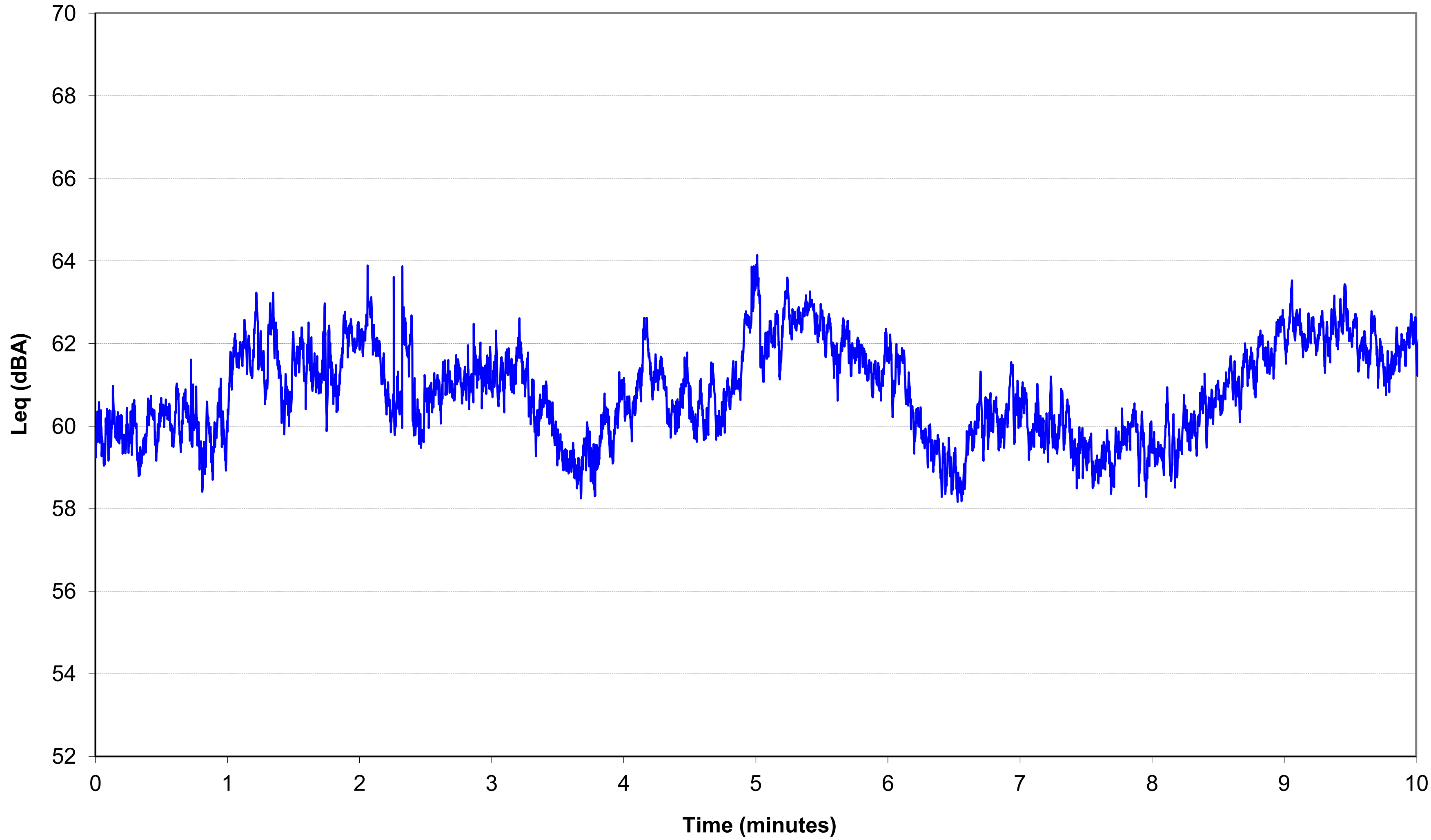


Figure 7. Time Variation of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pad for Site #2 - First 10 Seconds of Measurements

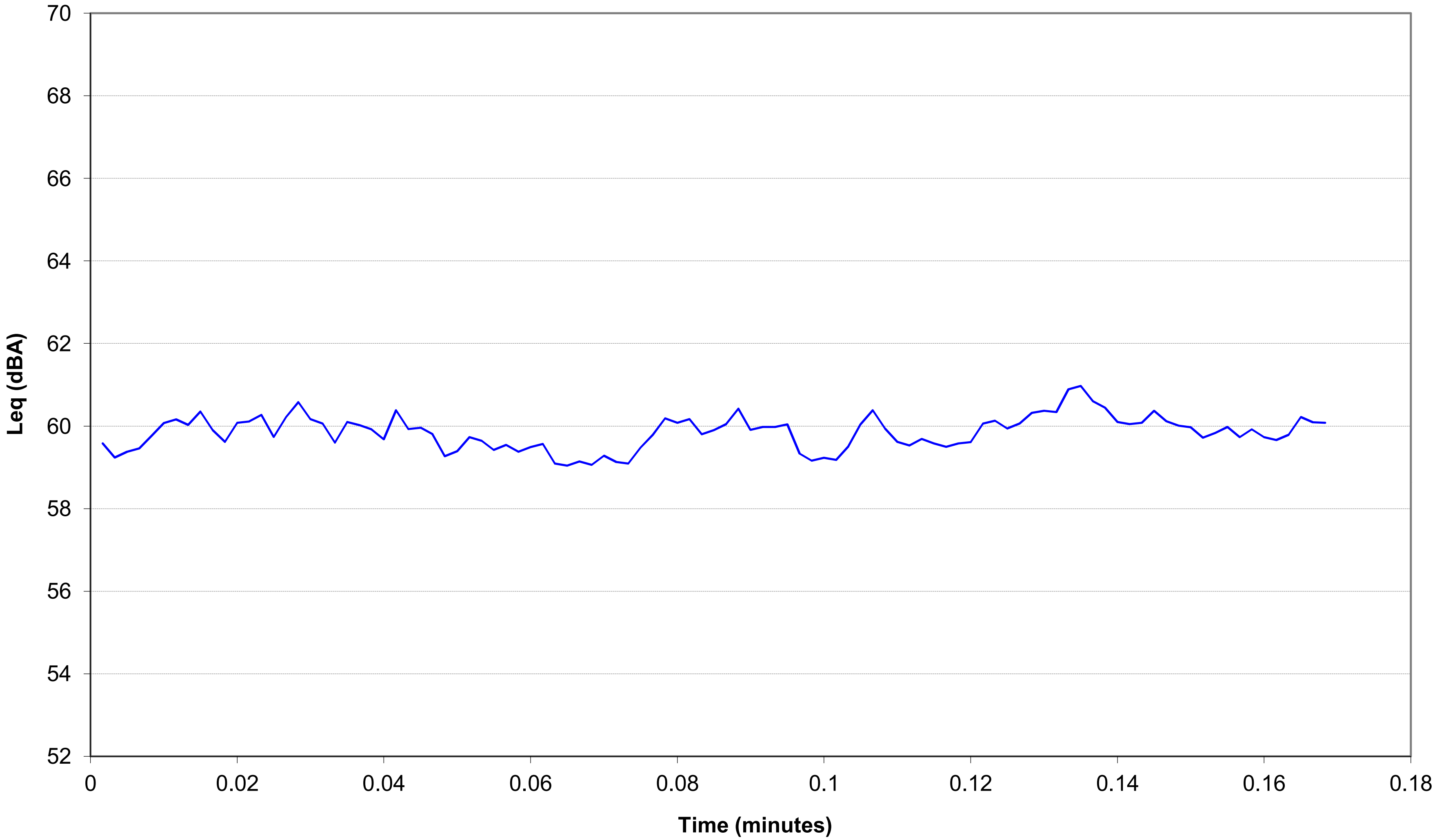
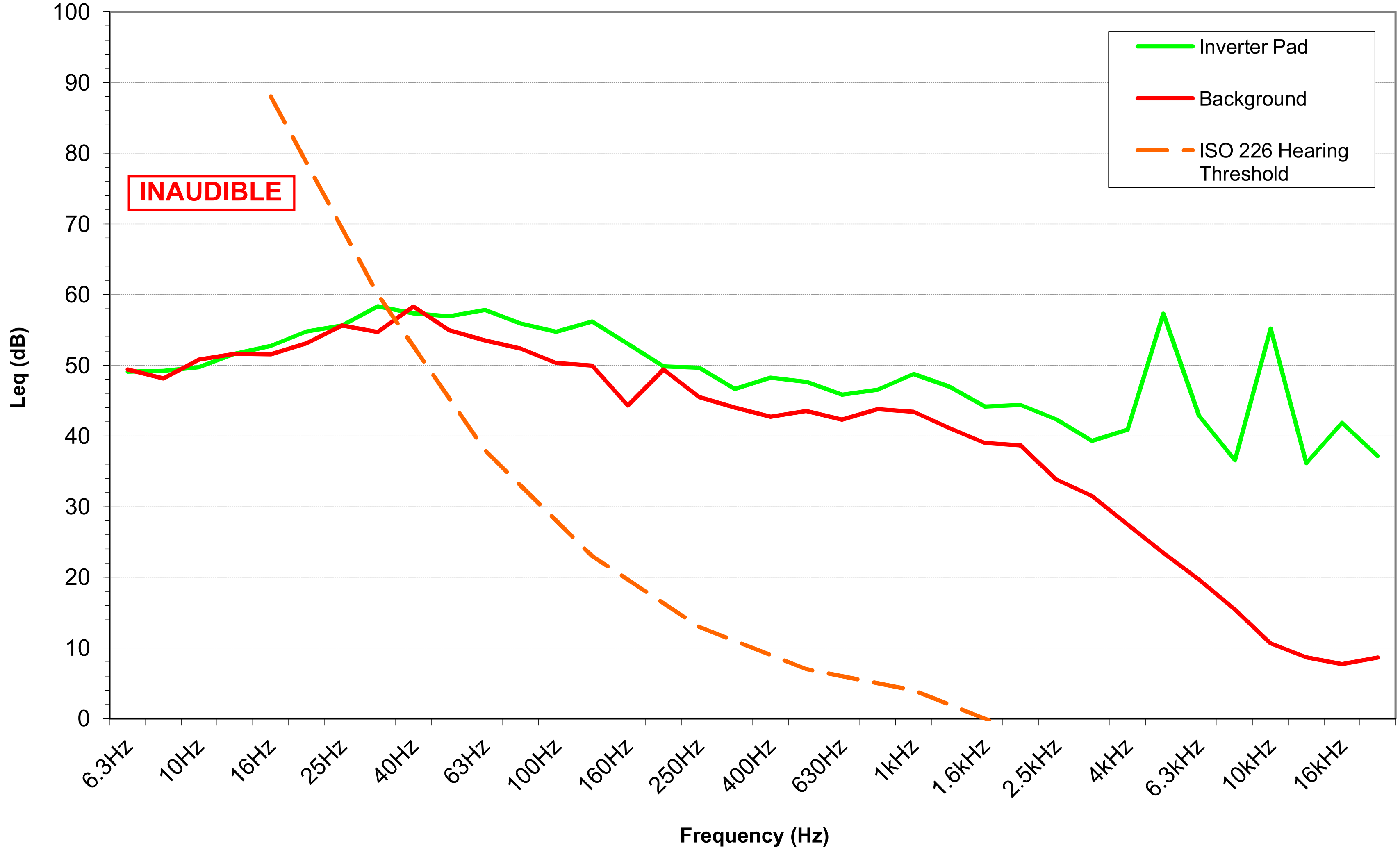


Figure 8. Frequency Spectrum of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pad at Site #2



3.3 Site 3 – Norfolk Solar

Facility Location:	33 Medway Branch Road, Norfolk, MA
Facility Owner:	Constellation Solar Massachusetts, LLC
System Capacity:	1,375 kW
Power Output During Monitoring:	1,200 to 1,375 kW
No. & Size Inverters:	(2) 500-kW inverters and (1) 375-kW inverter
Date Measured:	Monday October 22, 2012
Sky Cover:	10% (passing small cumulus clouds)
Winds:	West 10-12 mph
Ground:	One PV array sits high on top of the closed landfill with grass cover and no surrounding vegetation. The other, larger PV array is in a wooded area on relatively flat ground. Measurements were made at the larger PV array.
Background Sound:	Mean value L_{eq} of 45.3 dBA (range of 43.1 to 47.5 dBA). Mean value L_{90} of 42.5 dBA (range of 42.1 to 43.2 dBA). Sources included distant traffic noise and natural sounds.
Background EMF:	None (< 0.2 mG and < 5 V/m).

There are two solar photovoltaic arrays on the land of the Town of the Norfolk Department of Public Works. One array sits on top of a capped landfill and has a single equipment pad with one inverter. The second, and larger, array is in a cleared flat area east of the capped landfill and has a single equipment pad housing two inverters. The boundaries of the PV arrays are fenced. The surrounding area has only grass cover or low vegetation. Measurements were made at the larger PV array and at the equipment pad housing two inverters with a capacity of 875 kW. The sound and EMF measurements made at Site 3 are summarized in Tables 7 through 9. Figures 9 and 10 present a time series graph of 0.1-second L_{eq} sound levels at the nearest measurement location (1X) for the equipment pad, while Figure 11 provides the corresponding 1/3-octave band spectra for the sound level measurements at those same locations along with the spectrum for background sound levels.

<u>Sound Levels</u>

Background sound levels were fairly constant across the site and distant roadway traffic was the primary background sound source. The background mean value L_{eq} and L_{90} levels were 45.3 dBA and 42.5 dBA, respectively. The PV array was inaudible outside of the fenced boundary except at the South East boundary location where a faint inverter hum could be heard. Broadband sound levels at the locations set back 50 to 150 feet from the boundary are not elevated above background levels.

L_{eq} sound levels at a distance of 10 feet from the inverter face on the equipment pad (which holds two inverters) were 54.8 to 60.9 dBA. Along the axis perpendicular to the inverter face measured sound levels were 6 to 7 dBA higher than at the same distance along the axis parallel to the inverter face. The sound levels generally followed the expected hemispherical wave spreading law (approximately -6 dB per doubling of distance). At a distance of 150 feet, all inverter sounds were below background sound levels.

The time domain analysis presented in Figures 9 and 10 reveal that 0.1-second L_{eq} sound levels at the close distance of 10 feet generally varied 3 to 4 dBA. The graphs show no recurring pattern in the rise and fall of the inverter sound levels over the measurement period of ten minutes. Between 7 and 9 minutes into the 10-minute measurement, clouds passed over the face of the sun, power production dropped, and the inverter cooling fans turned off for a brief period, as shown by the abrupt 4 dBA drop in sound level in Figure 9.

The frequency spectrum of equipment sound at the close distance of 10 feet (Figure 11) shows energy peaks in four 1/3-octave bands: 63, 125, 5,000 and 10,000 Hz. The high frequency peaks produce the characteristic "ringing noise" or high-frequency buzz heard when one stands close to an operating inverter. The second frequency peak in each pair is a first-harmonic tone (10 kHz being twice the frequency of 5 kHz). The tonal sound exhibited by Figure 11 is not, however, audible at distances of 50 to 150 feet beyond the site boundary, and these tonal peaks do not appear in the background sound spectrum shown in Figure 11. The dashed line in Figure 11 is the ISO 226 hearing threshold and it reveals that low-frequency sound from the inverters below 40 Hz is inaudible, even at a close distance. The background sound spectrum declines smoothly with increasing frequency in the audible range except for a slight rise around 800 to 2,000 Hz caused by distant roadway traffic noise.

Electric Fields

Electric field levels along the PV array boundary, and at the locations set back 50 to 150 feet from the site boundary, are not elevated above background levels (< 5 V/m).

Magnetic Fields

Magnetic field levels along the PV array boundary were in the very low range, at or below 0.2 mG. Magnetic field levels at the locations 50 to 150 feet from the site boundary were not elevated above background levels (<0.2 mG).

Table 9 reveals that there are significant magnetic fields at locations a few feet from inverters, in the range of 150 to 500 mG. These levels drop back to levels of 0.4 mG in the perpendicular direction and to background levels (<0.2 mG) in the parallel direction at 150 feet from the inverters. The variation of magnetic field with distance shown in Table 9 generally shows the field strength is proportional to the inverse cube of the distance from equipment.

TABLE 7

SOUND AND EMF LEVELS MEASURED AT SITE 3
PV ARRAY BOUNDARY

Boundary Location	L_{90} Level (dBA)	L_{eq} Level (dBA)	Magnetic Field (mG)	Electric Field (V/m)
North West Boundary	46.2	48.3	< 0.2	< 5
South West Boundary	48.9	50.6	< 0.2	< 5
South East Boundary	43.3	44.3	0.2	< 5
North East Boundary	43.9	46.1	< 0.2	< 5
Background Mean Values	42.5	45.3	< 0.2	< 5
Set back 50 feet from Boundary	43.2	47.5	< 0.2	< 5
Set back 100 feet from Boundary	42.2	45.4	< 0.2	< 5
Set back 150 feet from Boundary	42.1	43.1	< 0.2	< 5

TABLE 8

**SOUND LEVELS MEASURED AT SITE 3
EQUIPMENT PAD**

Equipment Pad / Direction / Distance	L_{90} Level (dBA)	L_{eq} Level (dBA)
Perpendicular to Inverter Face / 10 feet	59.7	60.9
Perpendicular to Inverter Face / 20 feet	57.3	58.6
Perpendicular to Inverter Face / 30 feet	49.4	50.1
Perpendicular to Inverter Face / 150 feet	43.9	47.0
Parallel to Inverter Face / 10 feet	53.9	54.8
Parallel to Inverter Face / 20 feet	50.6	51.3
Parallel to Inverter Face / 30 feet	45.5	48.0
Parallel to Inverter Face / 150 feet	41.8	43.7

TABLE 9

**EMF LEVELS MEASURED AT SITE 3
EQUIPMENT PAD**

Equipment Pad / Direction / Distance	Magnetic Field (mG)	Electric Field (V/m)
Parallel to Inverter Face / 3 feet	150	< 5
Parallel to Inverter Face / 6 feet	10	< 5
Parallel to Inverter Face / 9 feet	5	< 5
Parallel to Inverter Face / 150 feet	< 0.2	< 5
Perpendicular to Inverter Face / 3 feet	500	< 5
Perpendicular to Inverter Face / 6 feet	200	< 5
Perpendicular to Inverter Face / 9 feet	80	< 5
Perpendicular to Inverter Face / 150 feet	0.4	< 5

Figure 9. Time Variation of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pad for Site #3

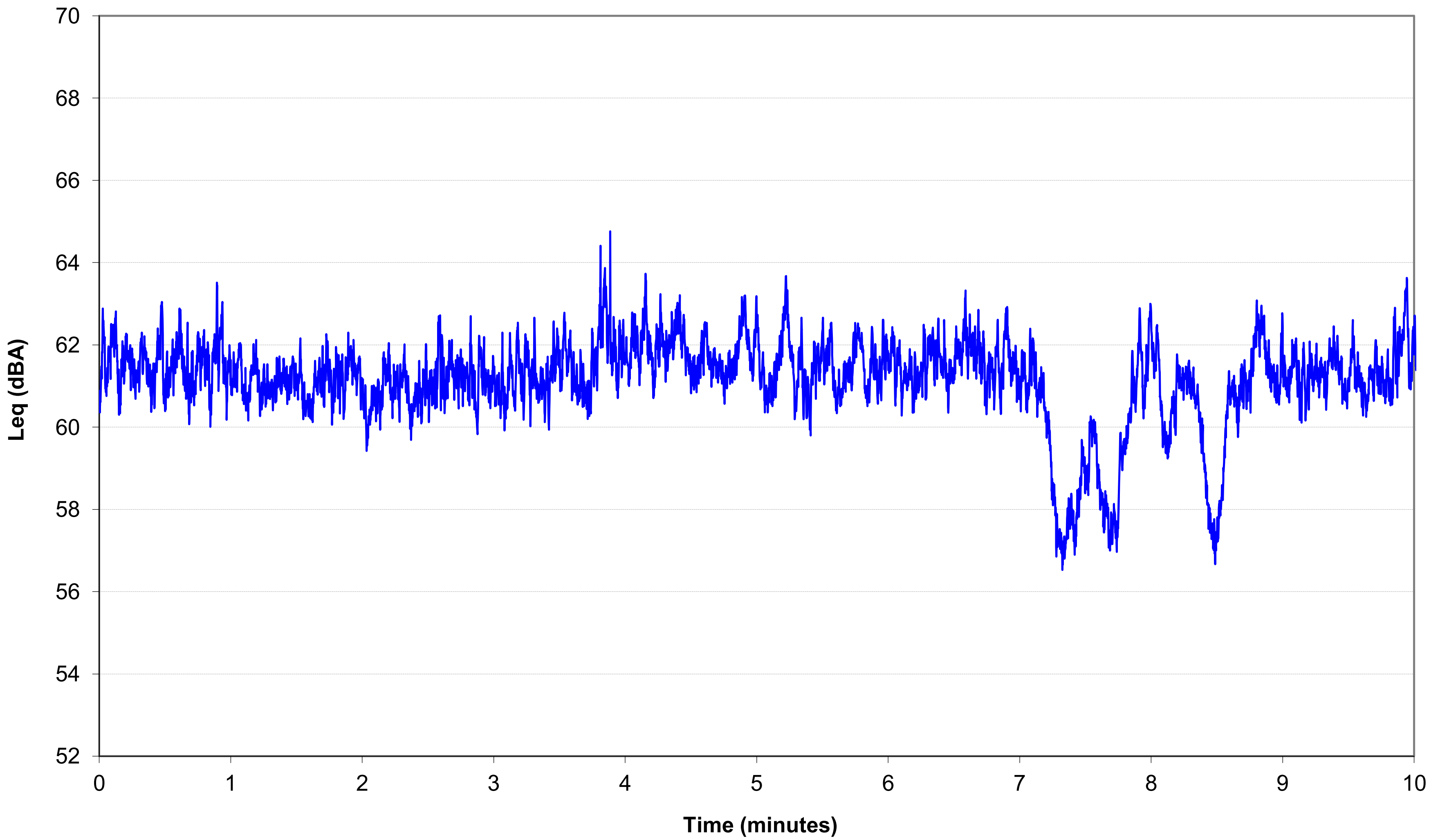


Figure 10. Time Variation of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pad for Site #3 - First 10 Seconds of Measurements

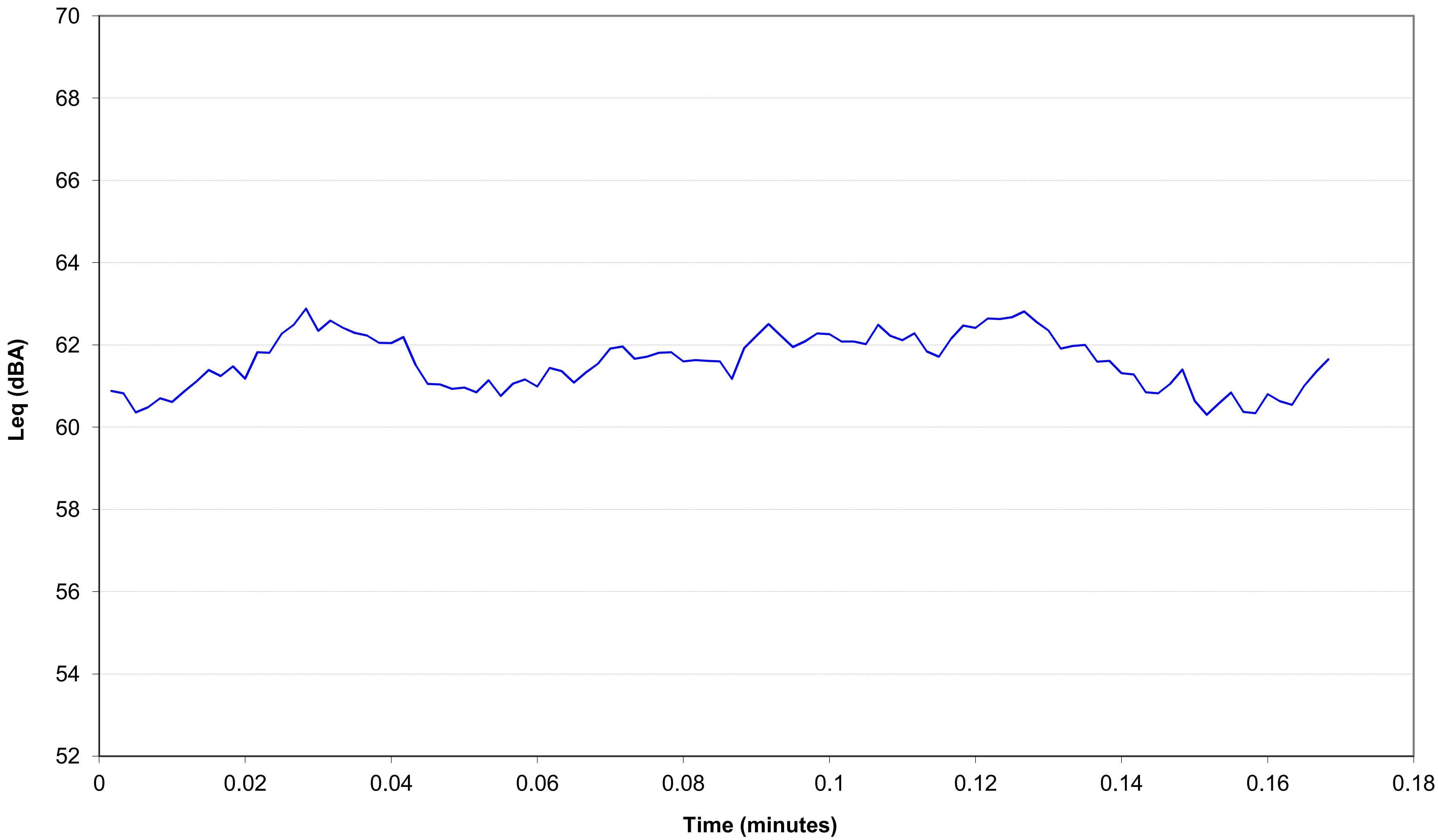
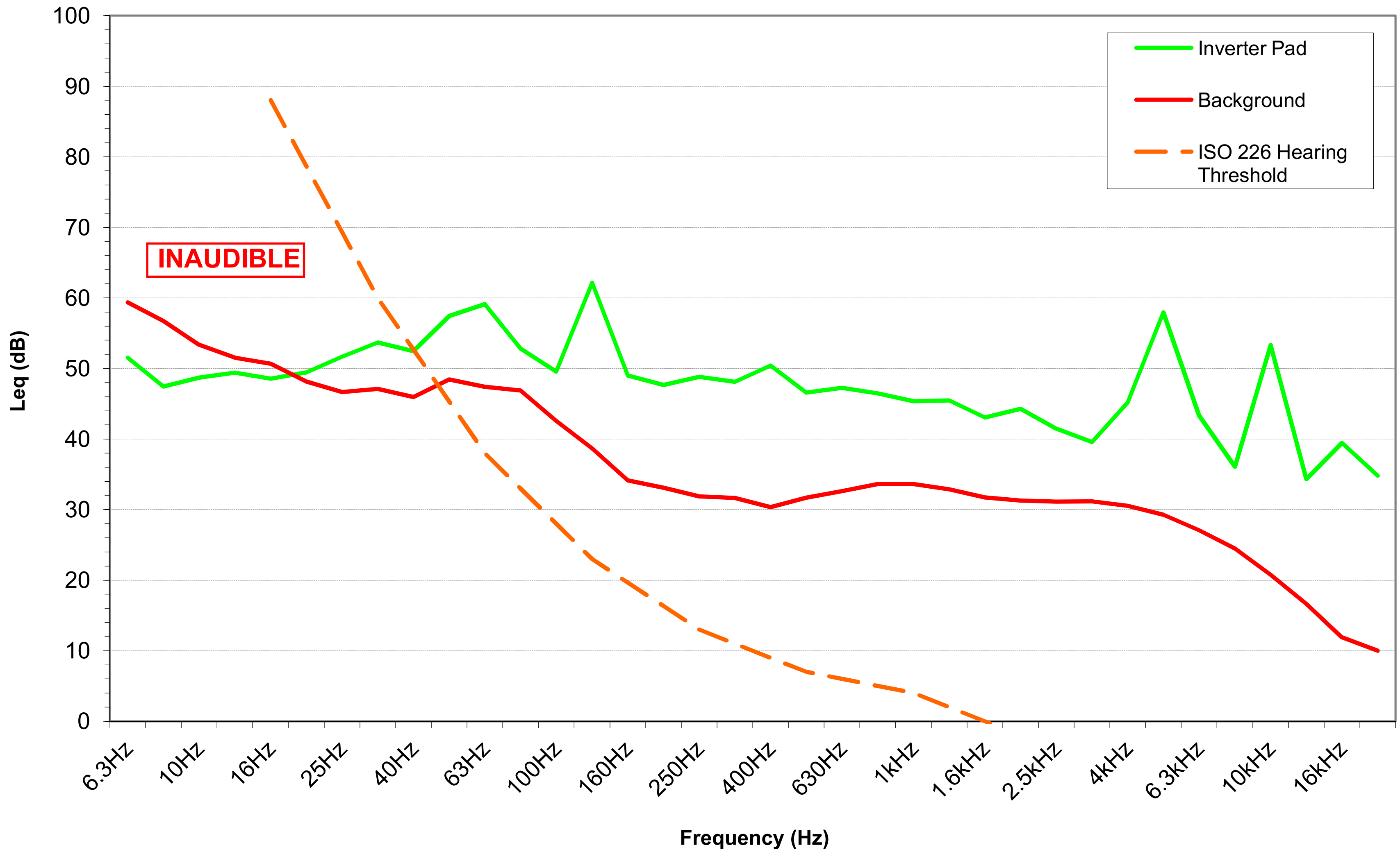


Figure 11. Frequency Spectrum of Sound Levels (Leq) at a Distance of 10 Feet from the Inverter Pad at Site #3



3.4 Site 4 – Residential Solar at Mass. Audubon Society in Sharon

Facility Location:	Moose Hill Sanctuary, 293 Moose Hill Road, Sharon, MA
Facility Owner:	Massachusetts Audubon Society
System Capacity:	8.6 kW
Power Output During Monitoring:	4.2 kW
No. & Size Inverters:	(1) 5-kW inverter and (1) 3.6-kW inverter
Date Measured:	Friday October 26, 2012
Sky Cover:	50% (scattered clouds)
Winds:	Northwest 0-3 mph
Ground:	(42) Evergreen solar panels are mounted on the pitched roof of the two-story building and face south. The ground around the site is cleared and opens to the south with surrounding woods at a distance.
Background EMF:	None in occupied rooms (< 0.2 mG and < 5 V/m). In the basement storage space where the inverters were housed, a background magnetic field of 2 mG was present and the background electric field was < 5 V/m.

EMF measurements were made inside the headquarters building of the Massachusetts Audubon Moose Hill Sanctuary. No sound measurements were made for this residential sized solar installation. The EMF measurements were made in rooms on the second floor of the building, the closest locations occupants have to the roof-mounted panels. Measurements were also made at the inverters inside the basement of the building, in a space not readily accessible to the public. The EMF measurements made at Site 4 are summarized in Tables 10 and 11.

Electric Fields

Electric field levels in the rooms on the top floor, nearest the roof-mounted solar panels are not elevated above background levels (< 5 V/m). In the basement, electric fields near the inverters (3 feet) are not elevated above background levels (< 5 V/m).

Magnetic Fields

Magnetic field levels in the rooms on the top floor, nearest the roof-mounted solar panels were in the very low range of 0.2 to 1.4 mG. Table 11 reveals that there are low-level magnetic fields at locations a few feet from inverters, around 6 to 10 mG. These levels dropped back to a floor of 2 mG at a distance of 6 to 9 feet from the inverters. Nearby electrical lines and other equipment in the basement created a background of 2 mG in the space where the inverters were housed.

TABLE 10

EMF LEVELS MEASURED INSIDE THE RESIDENTIAL BUILDING, TOP FLOOR AT SITE 4

Boundary Location	Magnetic Field (mG)	Electric Field (V/m)
North West Room	0.9	< 5
South West Room	1.4	< 5
South East Room	0.2	< 5
North East Room	0.5	< 5

TABLE 11

EMF LEVELS MEASURED INSIDE THE RESIDENTIAL BUILDING, BASEMENT AT SITE 4

Equipment Pad / Direction / Distance	Magnetic Field (mG)	Electric Field (V/m)
Parallel to Inverter Face / 3 feet	10	< 5
Parallel to Inverter Face / 6 feet	6	< 5
Parallel to Inverter Face / 9 feet	2	< 5
Parallel to Inverter Face / 15 feet	2	< 5
Perpendicular to Inverter Face / 3 feet	6	< 5
Perpendicular to Inverter Face / 6 feet	2	< 5
Perpendicular to Inverter Face / 9 feet	2	< 5
Perpendicular to Inverter Face / 15 feet	2	< 5

4.0 CONCLUSIONS

Sound pressure level and electromagnetic field (EMF) measurements were made at three utility-scale PV arrays with a capacity range of 1,000 to 3,500 kW under a full-load condition with sunny skies and the sun at approximately 40^{o} azimuth. Measurements were taken at set distances from the inverter pads and along the fenced boundary of the PV array. Measurements were also made at set distances back from the boundary. Broadband and 1/3-octave band sound levels were measured, along with the time variation of sound levels from the equipment.

EMF Measurements were also made at one residential[6] PV installation with a capacity of 8.6 kW under a partial-load condition. PV array operation is related to the intensity of solar insolation. Less sunshine results in lower sound and EMF levels from the equipment, and no sound or EMF is produced at night when no power is produced. A description of acoustic terms and metrics is provided in Appendix A, and EMF terms and metrics are presented in Appendix B. These appendices provide useful information for interpreting the results in this report and placing them in context, relative to other sound and EMF sources.

<u>Sound Levels</u>

At the utility scale sites, sound levels along the fenced boundary of the PV arrays were generally at background levels, though a faint inverter hum could be heard at some locations along the boundary. Any sound from the PV array and equipment was inaudible and sound levels are at background levels at set back distances of 50 to 150 feet from the boundary.

Average L_{eq} sound levels at a distance of 10 feet from the inverter face varied over the range of 48 dBA to 61 dBA for Site 2 and Site 3 Inverters[7], and were higher in the range of 59 to 72 dBA for Site 1 Inverters. Along the axis perpendicular to the plane of the inverter face and at distances of 10 to 30 feet, sound levels were 4 to 13 dBA higher compared to levels at the same distance along the axis parallel to the plane of the inverter face. At a distance of 150 feet from the inverter pad, sound levels

[6] Only EMF measurements were made at the residential site.

[7] The same make of inverters were used at Sites 2 and 3.

approached background levels. Sound level measurements generally followed the hemispherical wave spreading law (-6 dB per doubling of distance).

The time domain analysis reveals that 0.1-second L_{eq} sound levels at a distance of 10 feet from an inverter pad generally varied over a range of 2 to 6 dBA, and no recurring pattern in the rise and fall of the inverter sound levels with time was detected. The passage of clouds across the face of the sun caused cooling fans in the inverters to briefly turn off and sound levels to drop 4 dBA.

The 1/3-octave band frequency spectrum of equipment sound at the close distance of 10 feet shows energy peaks in several mid-frequency and high-frequency bands, depending on the inverter model. Tonal sound was found to occur in harmonic pairs: 63/125 Hz; 315/630 Hz; 3,150/6,300 Hz; and 5,000/10,000 Hz. The high frequency peaks produce the characteristic "ringing noise" or high-frequency buzz heard when one stands close to an operating inverter. The tonal sound was not, however, audible at distances of 50 to 150 feet beyond the PV array boundary, and these tonal peaks do not appear in the background sound spectrum. All low-frequency sound from the inverters below 40 Hz is inaudible, at all distances.

Electric Fields

The International Commission on Non-Ionizing Radiation Protection has a recommended exposure limit of 4,200 V/m for the general public. At the utility scale sites, electric field levels along the fenced PV array boundary, and at the locations set back 50 to 150 feet from the boundary, were not elevated above background levels (< 5 V/m). Electric fields near the inverters were also not elevated above background levels (< 5 V/m).

At the residential site, indoor electric fields in the rooms closest to the roof-mounted panels and at locations near the inverters were not elevated above background levels (< 5 V/m).

Magnetic Fields

The International Commission on Non-Ionizing Radiation Protection has a recommended exposure limit of 833 mG for the general public. At the utility scale sites, magnetic field levels along the fenced PV array boundary were in the very low range of 0.2 to 0.4 mG. Magnetic field levels at the locations

50 to 150 feet from the array boundary were not elevated above background levels (<0.2 mG). There are significant magnetic fields at locations a few feet from inverters, in the range of 150 to 500 mG. At a distance of 150 feet from these utility-scale inverters, these fields drop back to very low levels of 0.5 mG or less, and in many cases to background levels (<0.2 mG). The variation of magnetic field with distance generally shows the field strength is proportional to the inverse cube of the distance from equipment.

At the residential site, indoor magnetic field levels in the rooms closest to the roof-mounted panels were in the low range of 0.2 to 1.4 mG. There are low-level magnetic fields at locations a few feet from the inverters, in the range of 6 to 10 mG. At a distance of no more than 9 feet from the inverters, these fields dropped back to the background level at the residential site of 2 mG. Due to the relatively high background level in the residential site basement where the inverters were housed, the relationship of magnetic field strength to distance from the inverters could not be discerned.

APPENDIX A

ACOUSTIC TERMS AND METRICS

All sounds originate with a source – a human voice, vehicles on a roadway, or an airplane overhead. The sound energy moves from the source to a person's ears as sound waves, which are minute variations in air pressure. The loudness of a sound depends on the **sound pressure level**[8], which has units of decibel (dB). The **decibel scale** is logarithmic to accommodate the wide range of sound intensities to which the human ear is subjected. On this scale, the quietest sound we can hear is 0 dB, while the loudest is 120 dB. Every 10-dB increase is perceived as a doubling of loudness. Most sounds we hear in our daily lives have sound pressure levels in the range of 30 dB to 90 dB.

A property of the decibel scale is that the numerical values of two separate sounds do not directly add. For example, if a sound of 70 dB is added to another sound of 70 dB, the total is only a 3-decibel increase (or 73 dB) on the decibel scale, not a doubling to 140 dB. In terms of sound perception, 3 dB is the minimum change most people can detect. In terms of the human perception of sound, a halving or doubling of loudness requires changes in the sound pressure level of about 10 dB; 3 dB is the minimum perceptible change for **broadband** sounds, i.e. sounds that include all frequencies. Typical sound levels associated with various activities and environments are presented in Table A-1. The existing sound levels at a PV project site are determined primarily by the proximity to roads and highways, the source of traffic noise. Sound exposure in a community is commonly expressed in terms of the **A-weighted sound level (dBA)**; A-weighting approximates the frequency response of the human ear and correlates well with people's perception of loudness.

The level of most sounds change from moment to moment. Some are sharp impulses lasting one second or less, while others rise and fall over much longer periods of time. There are various measures of sound pressure designed for different purposes. The equivalent sound level $\mathbf{L_{eq}}$ is the steady-state sound level over a period of time that has the same acoustic energy as the fluctuating sounds that actually occurred during that same period. It is commonly referred to as the energy-average sound

[8] The sound pressure level is defined as $20*\log_{10}(P/P_o)$ where P is the sound pressure and P_o is the reference pressure of 20 micro-Pascals (20 μPa), which by definition corresponds to 0 dB.

level and it includes in its measure all of the sound we hear. EPA has determined that the **L_{eq}** average sound level correlates best with how people perceive and react to sound.[9]

To establish the background sound level in an area, the **L_{90}** metric, which is the sound level exceeded 90% of the time, is typically used. The **L_{90}** can be thought of as the level representing the quietest 10% of any time interval. The **L_{90}** is a broadband sound pressure measure. By definition, the **L_{90}** metric will filter out brief, loud sounds, such as intermittent traffic on a nearby roadway.

Sound pressure level measurements typically include an analysis of the sound spectrum into its various frequency components to determine tonal characteristics. The unit of frequency is **Hertz (Hz)**, measuring the cycles per second of the sound pressure waves. In the physiology of human hearing, every octave jump of a tone corresponds to a doubling of the sound frequency in Hz. For example, Middle-C on a piano has a frequency of approximately 260 Hz. High-C, one octave above, has a frequency of approximately 520 Hz. The hearing range for most people is 20 Hz to 20,000 Hz. In acoustic studies, the sound spectrum is divided into **octave bands** with center frequencies that are an octave apart, or 1/3-octave bands with center frequencies that are 1/3 of an octave apart. There are 11 whole octave bands centered in the audible range from 20 to 20,000 Hz. For the extended frequency range of 6.3 Hz to 20,000 Hz used in this study, there are 36 1/3-octave bands.

Low-frequency sound generally refers to sounds below 250 Hz in frequency, which is close to the tone of Middle-C on a piano. **Infrasound** is low-frequency sound at frequencies below 20 Hz, a sound wave oscillating only 20 cycles per second. For comparison, the lowest key on a piano produces a tone of 28 Hz, and human speech is in the range of 500 to 2,000 Hz. The hearing threshold for infrasound at 16 Hz is 90 decibels (dB).[10] We are enveloped in naturally occurring infrasound, which is inaudible. Infrasound is always present in the outdoor environment due to sounds generated by air turbulence, shoreline waves, motor vehicle traffic and distant aircraft.

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[9] U.S. Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," Publication EPA-550/9-74-004.

[10] International Standards Organization, ISO 226:2003.

TABLE A-1

VARIOUS INDOOR AND OUTDOOR SOUND LEVELS

Outdoor Sound Levels	Sound Pressure (μPa)		Sound Level (dBA)	Indoor Sound Levels
	6,324,555	-	110	Rock Band at 5 m
Jet Over-Flight at 300 m		-	105	
	2,000,000	-	100	Inside New York Subway Train
Gas Lawn Mower at 1 m		-	95	
	632,456	-	90	Food Blender at 1 m
Diesel Truck at 15 m		-	85	
Noisy Urban Area--Daytime	200,000	-	80	Garbage Disposal at 1 m
		-	75	Shouting at 1 m
Gas Lawn Mower at 30 m	63,246	-	70	Vacuum Cleaner at 3 m
Suburban Commercial Area		-	65	Normal Speech at 1 m
Quiet Urban Area -- Daytime	20,000	-	60	
		-	55	Quiet Conversation at 1m
Quiet Urban Area--Nighttime	6,325	-	50	Dishwasher Next Room
		-	45	
Suburban Area--Nighttime	2,000	-	40	Empty Theater or Library
		-	35	
Rural Area--Nighttime	632	-	30	Quiet Bedroom at Night
		-	25	Empty Concert Hall
Rustling Leaves	200	-	20	Average Whisper
		-	15	Broadcast and Recording Studios
	63	-	10	
		-	5	Human Breathing
Reference Pressure Level	20	-	0	Threshold of Hearing

Notes:
μPa - Micropascals describe sound pressure levels (force/area).
dBA - A-weighted decibels describe sound pressure on a logarithmic scale with respect to 20 μPa.

APPENDIX B

EMF TERMS AND METRICS

An electromagnetic field (**EMF**) is the combination of an **electric field** and a **magnetic field**. The electric field is produced by stationary charges, and the magnetic field by moving charges (currents). From a classical physics perspective, the electromagnetic field can be regarded as a smooth, continuous field, propagated in a wavelike manner. From the perspective of quantum field theory, the field is seen as quantized, being composed of individual particles (photons).

EMFs are present everywhere in our environment but are invisible to the human eye. For example, electric fields are produced by the local build-up of electric charges in the atmosphere associated with thunderstorms, and the earth's magnetic field causes a compass needle to orient in a North-South direction and is used for navigation. Besides natural sources, the electromagnetic spectrum also includes fields generated by man-made sources. For example, the electricity that comes out of every power socket has associated low frequency EMFs. A photovoltaic (PV) project generates low-frequency EMFs from inverters (that convert DC-current to AC-current), transformers (that step-up the PV project voltage), and current-carrying cables. The EMFs from PV project components are classified as "non-ionizing radiation," because the electromagnetic waves have low-energy quanta incapable of breaking chemical bonds in objects through which they pass.

The strength of the **electric field** is measured in volts per meter (**V/m**). Any electrical wire that is charged will produce an associated electric field. This field exists even when there is no current flowing. The higher the voltage, the stronger the electric field at a given distance from the wire. Magnetic fields arise from the motion of electric charges. The strength of the **magnetic field** is measured by the magnetic flux density in milli-Gauss (**mG**). In contrast to electric fields, a magnetic field is only produced once a device is switched on and current flows. The higher the current, the greater the strength of the magnetic field produced at a given distance. EMFs are strongest close to a source, and their strength rapidly diminishes with distance from it. Field strength is generally proportional to the inverse cube of the distance.

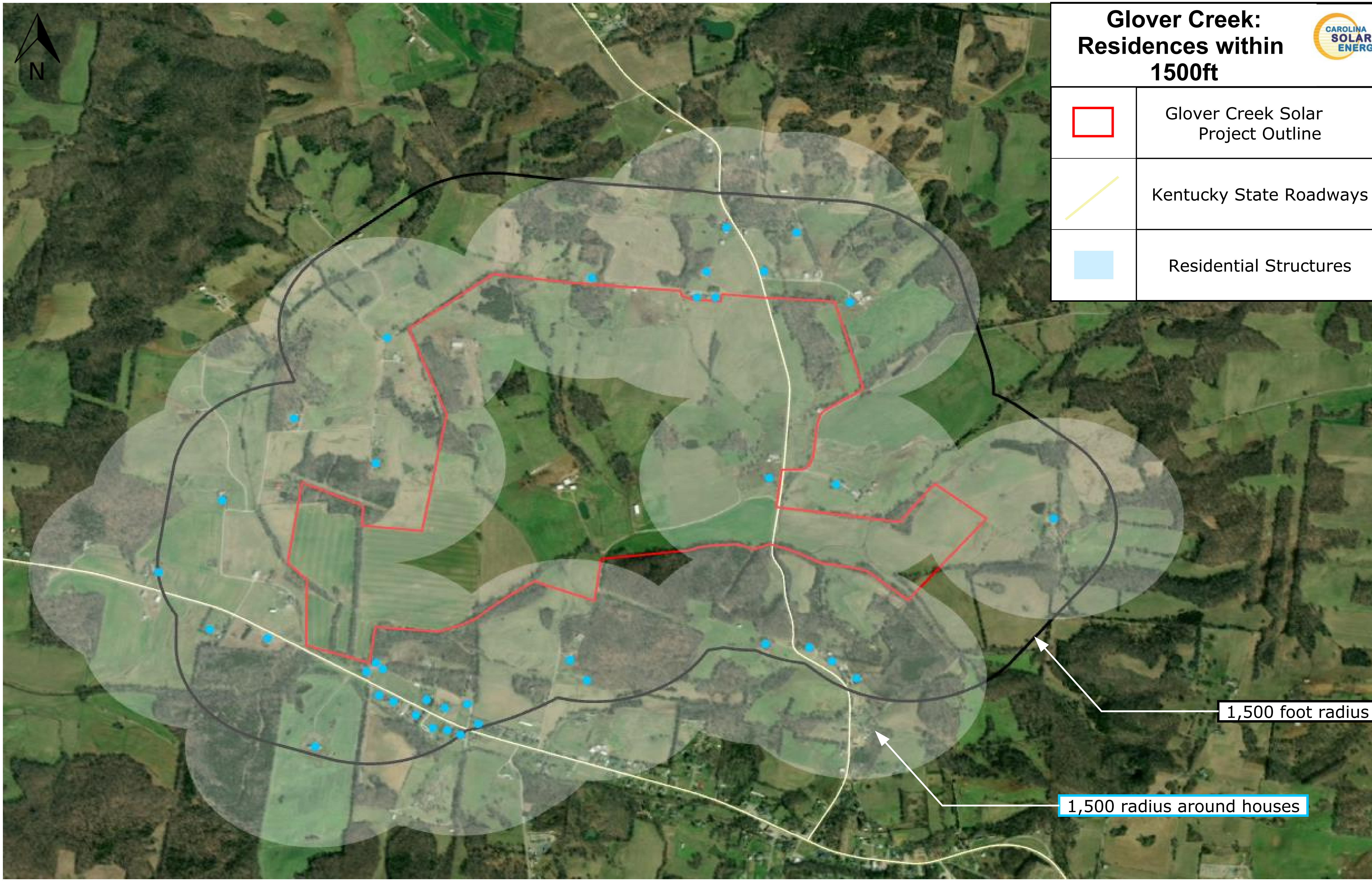
Typical household fixtures and appliances produce both types of fields. For example, at a distance of one foot from a fluorescent light, electric and magnetic fields of 50 V/m and 2 mG, respectively, are measured. At a distance of 1 inch from the power cord for an operating personal computer, fields of 40 V/m and 1 mG, respectively, are detected.

There are no federal, State or local regulatory exposure limits for electric or magnetic fields that apply to solar photovoltaic arrays. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has recommended exposure limits of 4,200 V/m and 833 mG for the general public. ICNIRP is an organization of 15,000 scientists in 40 nations who specialize in radiation protection, and their recommendations are routinely used in EMF exposure studies.

Exhibit 4 – Vegetative Buffer Cost Quotes (confidential)

Exhibit 5 – Fencing and Slat Cost Quotes (confidential)

Exhibit 6 – Project Map


N
Glover Creek: Residences within 1500ft
CAROLINA SOLAR ENERGY
Glover Creek Solar Project Outline
Kentucky State Roadways
Residential Structures
1,500 foot radius
1,500 radius around houses