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Overcoming Instrument Noise Floors When Measuring in Quiet Environments

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Abstract

In the absence of wind, water, animal- and human-related sounds, A-weighted sound levels in remote places drop to extremely low levels, and remain there over protracted periods of time. Using specialized, low-noise level instrumentation, A-weighted sound levels (A-levels) as low as 0 to 5 decibels have been measured on several occasions in Haleakala and Yellowstone National Parks. Presently, low-noise microphone systems are not designed to endure the elements for long-term, unattended monitoring applications. Proven, robust microphones that meet these requirements, however, have A-level noise floors on the order of 18 to 20 decibels. Thus, reported sound levels in quiet places often reflect instrumentation self-noise, not the environment to be measured.

This paper briefly reviews state-of-the-art microphone instrumentation, then focuses on methods for measuring low sound levels using these microphones with a 1/3-octave band frequency analyzer. Employing the self-noise (or noise floor) of the instrument as a reference, algorithms identify spectral regions compromised by instrument noise, and adjust or replace 1/3-octave band levels with probable values. Initial trials of this algorithm suggest that conventional microphone systems can be used to measure down to 5 decibels or less with less than 2 dB uncertainty in level.

1. Introduction

Sound levels in remote, quiet places, such as National Parks and other areas of historical and cultural significance, are coming into sharper focus as various agencies begin to define important acoustic resources to be protected. A typical means for quantifying sound levels in these places is continuous monitoring of the familiar A-weighted sound level, or A-level. However, unlike urban areas the sound levels often drop below the measuring instrument's internal electrical noise floor. The goal of this paper is to demonstrate how, through 1/3-octave band monitoring, A-levels as low as 5 dB may be measured with small uncertainties of estimation using common electret microphones.

2. Illustration of the Noise Floor Problem

Figure 1 shows a typical diurnal pattern of hourly L_{50} and L_{90} sound levels (sound levels exceeded 50 and 90 percent of the time, respectively) over a 4-day period. Measurements were made using a conventional ½-inch electret microphone with a manufacturer-stated A-level noise floor of 18 decibels. For lengthy periods each day reported sound levels hover about the 18 dB noise floor. Thus, instrumentation noise, not the actual sound level is being displayed during these times.

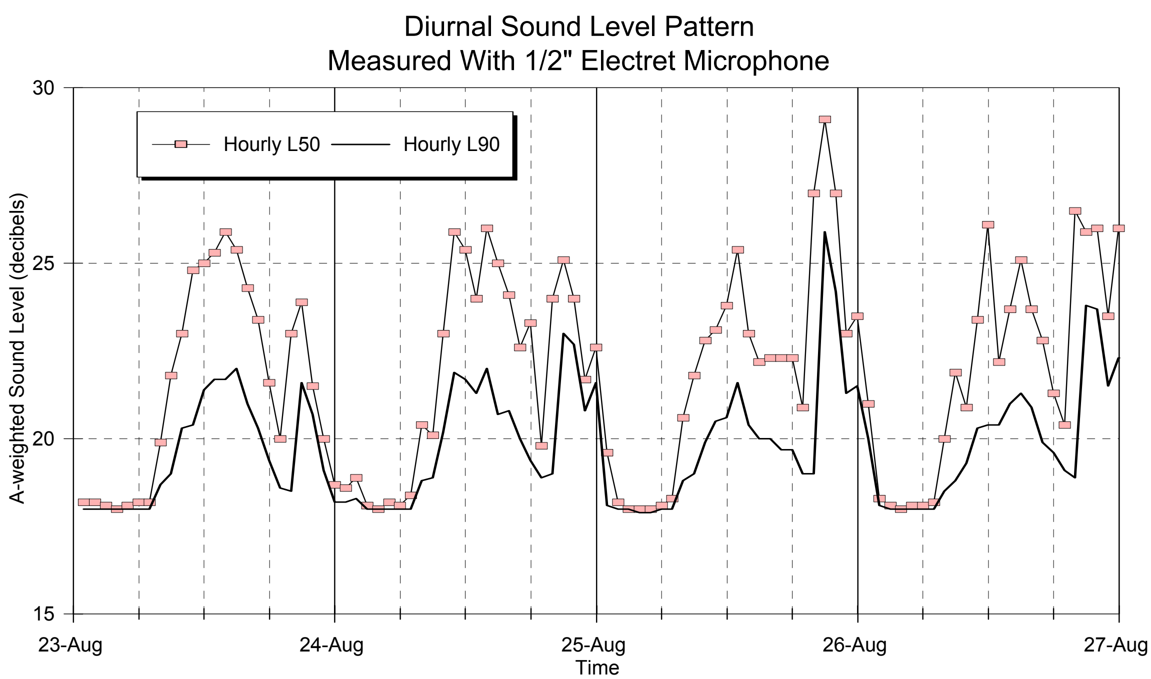

Figure 1. Typical Diurnal Pattern in Quiet Places

The cause of the problem illustrated in Figure 1 is identified in Figure 2. This figure shows the spectral content of a typical low sound level ambient environment (square symbols) along with the noise floor of the ½-inch electret microphone measurement system (circles). The example ambient was measured using a very low-noise microphone system in a remote area of Grand Canyon National Park. The A-level is 12.1 decibels. The triangles show the effect of summing the two spectra to illustrate what *would have been* measured using the electret microphone. In this typical low-ambient illustration low frequencies are essentially unaffected by the electret instrument noise. *Above* approximately 800 Hz instrument noise completely controls the measured spectral content.

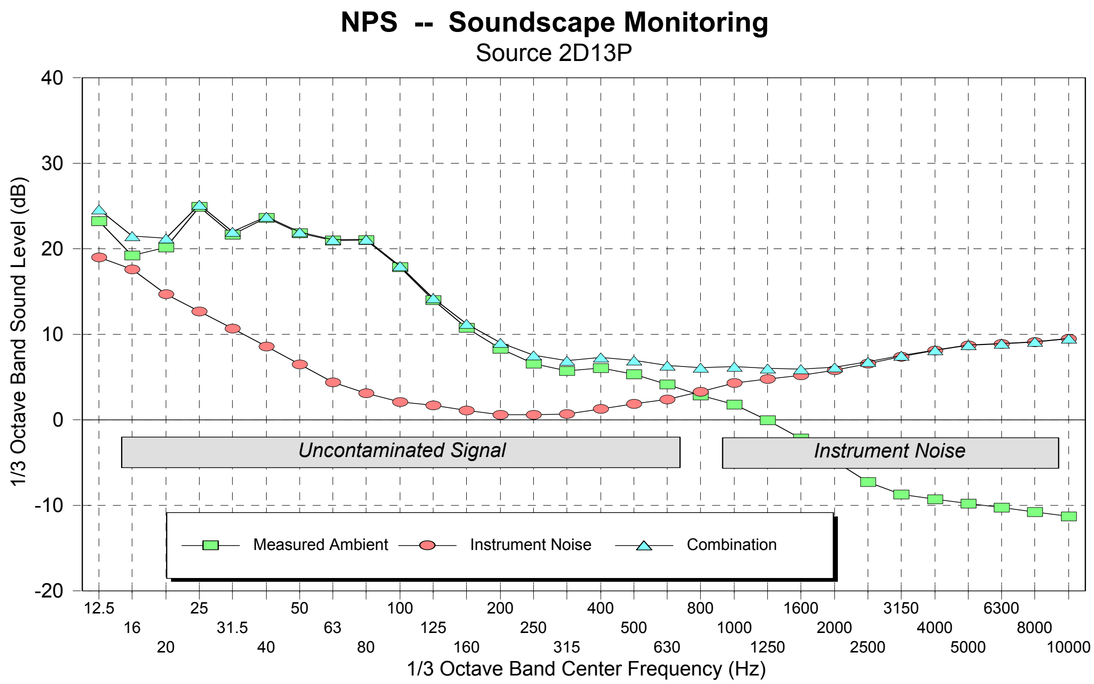

Figure 2. 1/3-Octave Band Example of Noise Floor Contamination

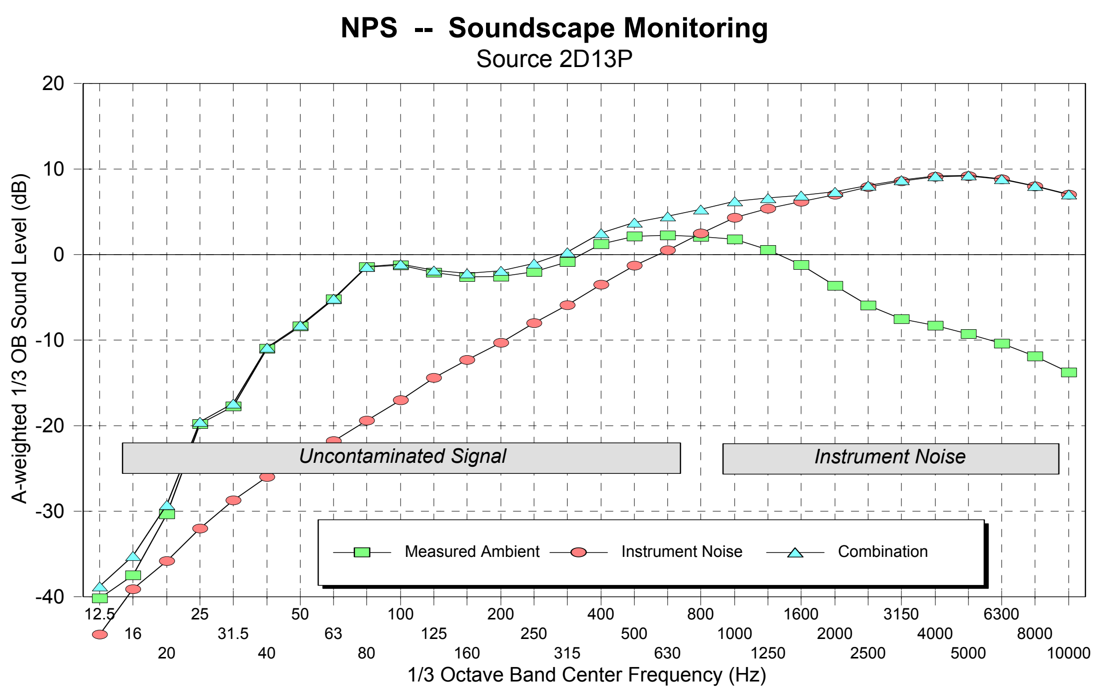

Figure 3. 1/3-Octave Band Example of Noise Floor Contamination (All Spectral A-weighted)

In Figure 3 all of the spectra in Figure 2 have been A-weighted. This figure shows that: (1) high frequency electret microphone noise controls its A-level noise floor, (2) mid frequencies generally control the true ambient A-level, and (3) even if the very low frequencies were contaminated by instrument noise (even by as much as 5 or 10 decibels), it is unlikely the measured A-level would be affected by more than ½ decibel. The foregoing suggests that a method for approximating contaminated high frequency sound levels would allow for the 1/3-octave band computation of a very reasonable approximation to the true A-level.

3. The Spectral Adjustment Algorithm

The example shown in Figures 2 and 3 is typical of virtually all instrument noise contaminated signals *in quiet places*. The proposed spectral adjustment algorithm uses a priori knowledge that the true spectrum shape is most likely downward sloping at high frequencies. If instrument noise were to be replaced by a reasonable approximation to the downward slope, uncertainties in the *exact* sound levels in the high frequency bands might have little effect on the uncertainty in the A-level computed from such a reconstructed spectrum. A 5-step adjustment procedure was developed to test this assumption:

1. Independently determine the 1/3-octave band instrument noise floor of the microphone / preamplifier system,
2. Using the measured noise floor, adjust by energy subtraction the sound levels in frequency bands where the measured band sound level is at least 1 decibel greater than the noise floor,
3. Determine the frequency band above which the subtraction criterion is no longer met,
4. Starting with the last (highest frequency) adjustable band, extrapolate the spectrum downward using a constant slope out to the 10,000 Hz band.
5. A-weight the reconstructed spectrum to compute an estimated A-weighted sound level.

4. Testing the Procedure

The above algorithm was tested in a spreadsheet format using the previously shown instrument noise and a collection of L_{90} spectra measured with the low-noise microphone in Grand Canyon and Haleakala National Parks. L_{90} spectra were chosen because they are low in level and therefore provide good tests for the algorithms.

4.1. Obtaining Sample Spectra for the Test

The recording systems used to acquire the test spectra incorporated a Bruel & Kjaer (B&K) Model 4179 1-inch diameter microphone and Model 2660 preamplifier. The A-weighted noise floor is on the order of 0 to 2 dB. A decading amplifier, and 16-bit digital audio tape recorder (DAT) completed the system. The recorded tapes were played back into a Larson Davis Model 2900 1/3-octave band analyzer employing "slow" sound level meter dynamics, and spectra were obtained from the analyzer at 1-second intervals.

Figure 4 shows ten source spectra from various park locations. They cover a range of spectral shapes and A-weighted sound levels (from 3 to 34 dB). For comparison, the ISO standard pure tone threshold of hearing curve is also shown. These ambients can be *very* quiet.

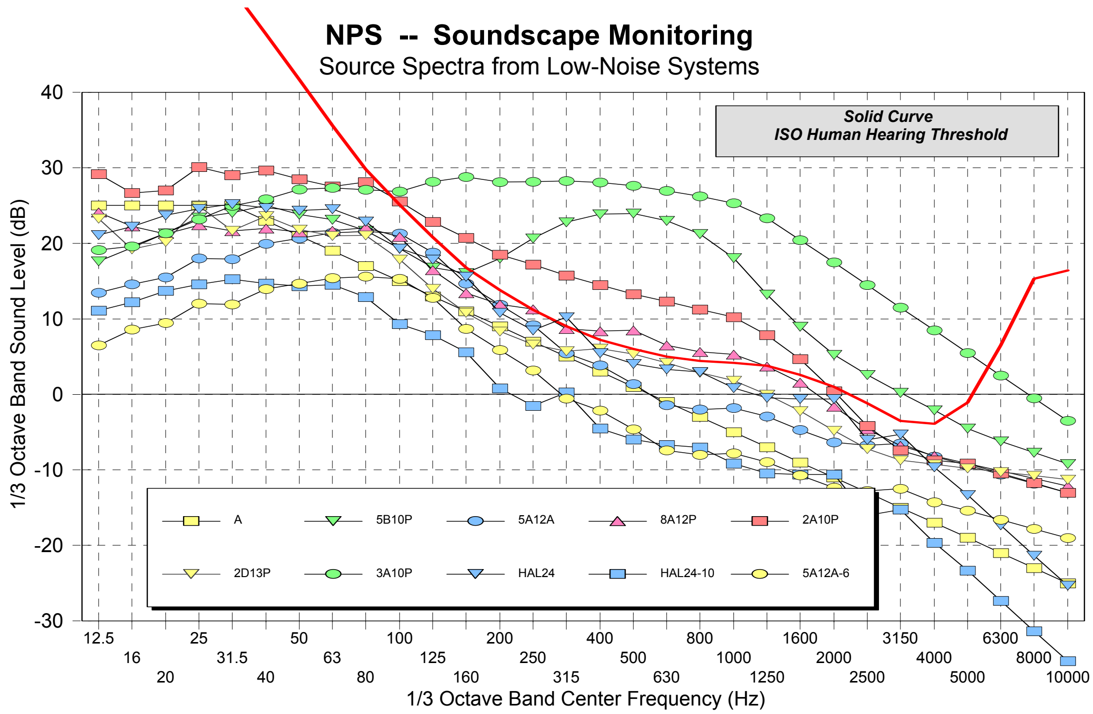

Figure 4. Low-Level Ambient Spectra Used For Testing Algorithm

4.2. Contaminating the Spectra

The measured 1/3-octave band instrument noise floor (shown in Figure 2) was energy-summed with each of the noise-free spectra of Figure 4 to synthesize noise floor contaminated spectra. A-levels for each of the contaminated spectra were calculated from the 1/3-octave band levels. These contaminated spectra served as the basis for testing the reconstruction algorithm.

4.3. The Spectral Reconstruction Method

Figure 5 shows the reconstruction steps, using the spectrum identified as "5A12A" in Figure 4. The original, uncontaminated spectrum is plotted as shaded squares (A-level = 11.7 dB). The hourglass symbols show the instrument noise floor (A-level = 18.4 dB). The shaded circles show the result of combining the two. The A-level of the contaminated spectrum is 19.2 dB, or 7.5 dB above the actual. The triangles represent the reconstructed spectrum using the algorithm described in the paragraph below.

Starting with the lowest frequency band, the contaminated 1/3-octave band sound level is compared with the noise floor value. If the difference is 1 decibel or greater the noise floor sound pressure level (SPL) is energy subtracted from the potentially contaminated value to produce a reconstructed SPL. In this illustration, above 800 Hz the difference between the contaminated levels and the noise floor becomes less than 1 decibel. At this point the algorithm assumes the energy subtraction scheme is too error prone, and continues the reconstruction process assuming the band sound levels simply drop at a constant rate of -2.5 dB per 1/3-octave band. This slope is an empirically derived estimate from the data in Figure 4. The important observation to be made here is that for both the reconstructed and original spectra, sound levels at frequencies greater than 1,600 Hz are of little consequence in determining the A-weighted level. As a result, the reconstructed A-level of 11.0 dB from the triangle spectrum is within 0.7 decibel of the true, uncontaminated value

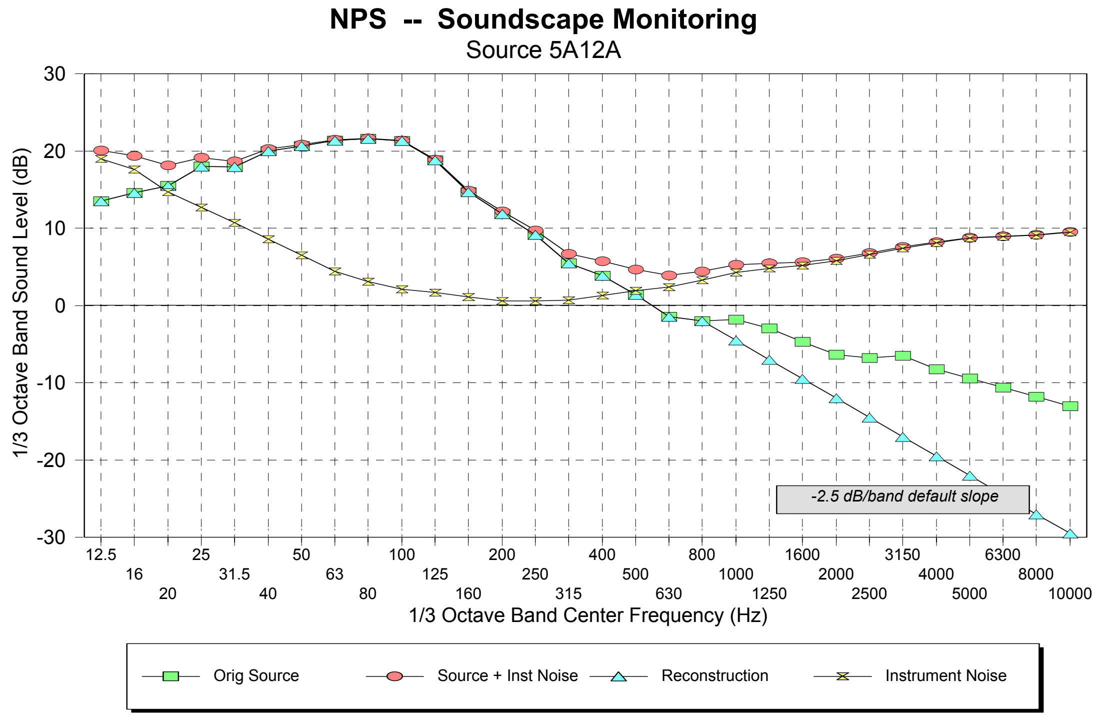

Figure 5. Spectral Contamination and Reconstruction Example

4.4. Sensitivity to Critical Parameters

A test was conducted of the sensitivity of this method to two critical parameters:

(1) The slope of the assumed ambient spectrum at the higher frequencies, and
(2) The uncertainty in the instrument noise floor.

Three values were chosen to cover a reasonable range for each parameter: (1) extrapolation slopes of 2.0, 2.5, and 3.0 dB per band, and (2) the measured noise floor, another 0.5 decibel higher in all bands, and one 0.5 decibel lower in all bands. Taken together, this 3-by-3 matrix applied to each contaminated spectrum produced nine different reconstructed A-level values.

For reporting purposes the highest and lowest of the nine reconstructed values for each spectrum were chosen. Their deviations from the actual A-levels are plotted in Figure 6. The deviation is plotted on the vertical axis and the true A-level is plotted on the horizontal. A normal and inverted triangle, one above the other, is shown for each spectrum. The inverted triangle indicates the largest amount by which the reconstructed A-level *overestimated* the true A-level.

The normal triangle indicates the largest amount by which the reconstructed A-level *underestimated* that of the original. As may be seen, the method results in estimation errors of less than 2 decibels down to actual measured A-levels of only 5 decibels.

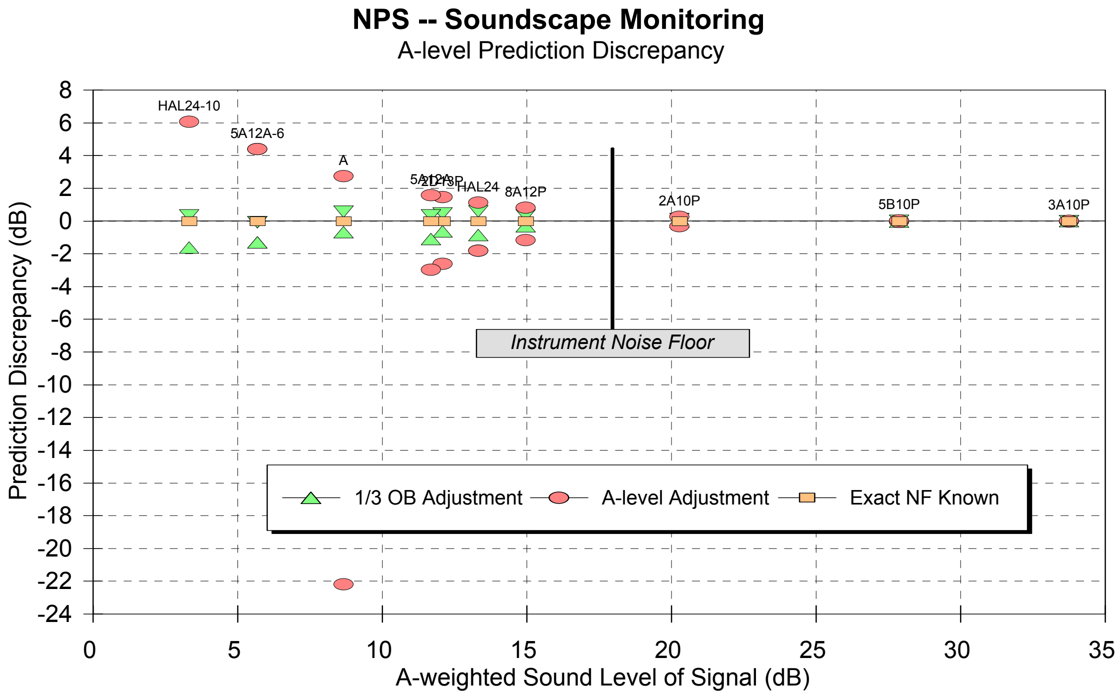

Figure 6. Estimation Accuracy

Could the same degree of precision be achieved by simply energy subtracting the A-level of the instrument noise from that of the contaminated signal, thus avoiding the spectral algorithm altogether? The circular plotting symbols answer this question. Two circles, one of positive value the other negative, are shown for each spectrum. The pair reflects the uncertainty in knowing the instrument noise floor exactly. The upper symbol plots the effect of under-estimating the noise floor by 0.5 decibel, and the lower one the effect of over-estimating the noise floor by 0.5 decibel and subtracting too much.

5. Observations and Conclusions

Long term monitoring of low ambient sound levels in Parks and other remote areas requires special consideration of both the measurement instrumentation and data analysis methods if accurate measurements are to be obtained. Robust, low-power consumption instrumentation, ideally suited to the rigors of unattended monitoring over a broad range of environmental conditions, does not possess the low self-noise needed to measure low sound levels found in these areas. In the absence of wind-induced noise in nearby foliage, or noise produced by moving water, there is little in remote areas to raise the ambient sound level much above the human threshold of hearing. As such, a combination of measurement technique and data analysis protocol is needed to deliver reliable measurement results under these conditions.

The 1/3-octave band data acquisition protocol combined with the spectral reconstruction method tested here was tailored to empirical sound level observations observed under a variety of low ambient conditions. Hence, the reconstruction method's only intended application is for these particular circumstances. The method has not been tested, nor is it intended for use in other applications, such as with instruments of higher self-noise or under ambient conditions where it is known that high frequency energy may dominate the A-weighted sound level. It is expected that when the latter condition exists, the sound levels will exceed the instrument noise and not require the special treatment described herein. But under the wide variety of low-level ambient conditions tested, measurement by 1/3-octave band combined with a data processing algorithm similar to the one described in this paper, will allow remarkably accurate measurements to be made down to A-weighted sound levels of 5 decibels with less than 2 decibels or less measurement uncertainty. *Without* such an algorithm the measurements provide no information whatsoever about sound levels in the single digit range. *With* the algorithm it is possible to obtain sound level information in the single digit range, but the answer comes at the price of a small error of estimation. The magnitude of this error seems acceptably small compared with the alternative of collecting no data whatsoever in this sound level range.

6. Acknowledgements

This work was supported by the Department of the Interior, National Park Service. Their assistance, suggestions and comments are gratefully acknowledged.