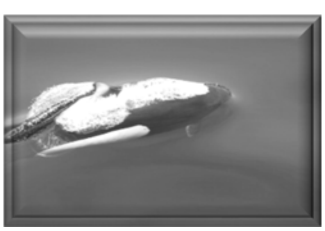
Manual for Optional WEB CALCULATOR Tool (Version 1.0) for:

2018 Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0)

Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts

Office of Protected Resources
National Marine Fisheries Service
Silver Spring, MD 20910



Recommended citation:

National Marine Fisheries Service. 2020. Manual for Optional Web Calculator Tool (Version 1.0) for: 2018 Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. Silver Spring, Maryland: Office of Protected Resources, National Marine Fisheries Service.

Photo Credits:

Bearded seal (*Erignathus barbatus*), Phocid pinniped Photo: John Jansen (NOAA)
Dall's porpoise (*Phocoenoides dalli*), High-frequency cetacean Photo: Kate Stafford (NOAA)
Bottlenose dolphin (*Tursiops truncatus*), Mid-frequency cetacean Photo: Allison Henry (NOAA)
California sea lion (*Zalophus californianus*), Otariid pinniped Photo: Sharon Melin (NOAA)
North Atlantic right whales (*Eubalaena glacialis*), Low-frequency cetacean Photo: NOAA

Direct questions regarding this User Manual or optional Web Calculator tool to: Amy Scholik-Schlomer (amy.scholik@noaa.gov).

TABLE OF CONTENTS

FIGURES

TABLES

ABBREVIATIONS, ACRONYMS, AND SYMBOLS

a	Low-frequency exponent
ANSI	American National Standards Institute
b	High-frequency exponent
BOEM	Bureau of Ocean Energy Management
C	Weighting function gain (dB)
dB	Decibel
-dB	Weighting function amplitude
f_1	Low-frequency cutoff (kHz)
f_2	High-frequency cutoff (kHz)
FM	Frequency modulated
FR	Federal Register
$E_{aud}(f)$	Exposure function
ESA	Endangered Species Act
h	hour
H	water depth
HF	High-frequency
Hz	Hertz
in	Inch
in^3	Cubic inches
ISO	International Organization for Standardization
K	Exposure function gain (dB)
kHz	Kilohertz
km	kilometers
LF	Low-frequency
$L_{0\text{-pk}}$	Peak sound pressure level
$L_{0\text{-pk,flat}}$	Peak sound pressure level (unweighted)
$L_{E,\ 24}$	Sound exposure level, cumulative 24h
log	logarithm
L_{rms}	Root Mean Square sound pressure level
MF	Mid-frequency
m	meter
MMPA	Marine Mammal Protection Act
msec	milliseconds
NA	Non-applicable
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OCW	Other Marine Carnivores in Water
OTO	One-third octave levels
OW	Otariids in water
Pa	Pascals
PCW	Phocid Carnivores in Water
PK	Peak sound pressure level
PL	Propagation loss
PSD	Power spectral density levels
PTS	Permanent Threshold Shift
PW	Phocids in water
R	Range from source
RMS	Root Mean Square sound pressure level
SEL	Sound exposure level
SEL_{cum}	Cumulative sound exposure level
SEL_{ss}	Single ping/pulse/strike/shot sound exposure level
SL	Source Level
SPL	Sound Pressure Level
TL	Transmission loss
TTS	Temporary Threshold Shift
VHF	Very high-frequency
VLF	Very low-frequency
$W_{aud}(f)$	Auditory weighting function
WFA	Weighting factor adjustments

MANUAL FOR OPTIONAL WEB CALCULATOR TOOL (VERSION 1.0)

I. INTRODUCTION

NOAA's National Marine Fisheries Service (NMFS) recognizes that the permanent threshold shift (PTS) onset thresholds expressed as weighted cumulative sound exposure level (SEL_{cum}) and peak sound pressure (PK) level metrics provided in the 2018 Revised Technical Guidance (NMFS 2018a; summarized in Appendix A of this Manual) are more complex than NMFS' previous thresholds and that different action proponents may have different levels of modeling capabilities. Thus, NMFS has provided a companion optional Web Calculator[1] tool for those action proponents unable to implement the 2018 Revised Technical Guidance's thresholds via other means.

There is no obligation to use the optional Web Calculator tool. The use of more sophisticated exposure modeling or consideration of additional activity-, source-, or location-specific factors, if possible, is encouraged. Appendix D of the 2018 Revised Technical Guidance (NMFS 2018a) provides more information on the methodologies, associated with the optional Web Calculator tool.

> **NOTE**: The optional Web Calculator tool provides a means to estimate distances (isopleths) associated with the 2018 Revised Technical Guidance's PTS onset thresholds. Mitigation and monitoring requirements associated with a Marine Mammal Protection Act (MMPA) authorization or an Endangered Species Act (ESA) consultation or permit are independent management decisions made in the context of the proposed activity and comprehensive effects analysis, and are beyond the scope of the 2018 Revised Technical Guidance and the Web Calculator tool.

1.1 ORIGIN OF OPTIONAL WEB CALCULATOR TOOL

As part of the review of the 2016 Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (2016 Technical Guidance; NMFS 2016), under Executive Order 13795, the Secretary of Commerce, in approving NMFS' issuance of a 2018 Revised Technical Guidance document (NMFS 2018a), recommended NMFS conduct a public comment period NMFS' newly drafted User Manual (NMFS 2018b) that accompanied our revised optional User Spreadsheet tool (Version 2.0). Based on feedback from the User Manual's public comment period (NOAA 2018), NMFS decided to create a more user-friendly and intuitive version of the optional User Spreadsheet tool that was web-based.

1.2 COMPARISON TO SOUTHALL ET AL. 2019

The PTS onset thresholds and marine mammal auditory weighting functions provided in the Technical Guidance (NMFS 2018a) directly adopts the methodology the Navy, via Dr. James Finneran, proposed for their Phase III Environmental Impact Analysis for testing and training activities (Finneran 2016).

Furthermore, Dr. Finneran's methodology, via a parallel process, is adopted in the update to Southall et al. 2007 (Southall et al. 2019). Thus, the thresholds and weighting functions between NMFS 2018a, Finneran 2016, and Southall et al. 2019 are nearly identical. However, Southall et al. (2019) adopts an updated and slightly modified approach for segregating marine mammals into hearing groups, as well as naming these hearing groups (i.e., essentially species formerly classified as MF cetaceans in Southall et al. 2007 are now classified as HF cetaceans in Southall et al. 2019, and species formerly classified as HF cetaceans in Southall et al. 2007 are now classified as Very High-Frequency (VHF) cetaceans in Southall et al. 2019; Table 1).

NMFS will continue to rely upon the marine mammal hearing group categorizations provided in the 2018 Revised Technical Guidance (NMFS 2018a), until a subsequent revision to this document is necessary.

[1] The optional Web Calculator tool is a web-based version of NMFS' optional User Spreadsheet tool (Excel). Action proponents are free to use either of these optional tools. However, the web-based version was designed to be more intuitive and user-friendly. The optional We Calculator tool can be found at: [Web Tool Link]

At this time, NOAA recommends when action proponents refer to a marine mammal hearing group that they specify what publication that hearing group is based upon (i.e., Southall et al. 2019 or NMFS 2018a).

Table 1: Comparison of marine mammal hearing groups between Southall et al. 2019 and NMFS 2018a.

Family/Genera/Species Included	Southall et al. 2019 Hearing Group	NOAA 2018 Hearing Group	NOAA 2018 Weighting Function
Balaena mysticetus; *Balaenoptera musculus; Balaenoptera physalus; Eubalaenidae* spp.	LF+ cetaceans	**LF Cetacean**	**LF Cetacean**
All other baleen whales	LF Cetaceans	**LF Cetacean**	**LF Cetacean**
Physeter macrocephalis; *Orcinus orca*; Ziphiidae	HF^ Cetaceans	**MF Cetaceans**	**MF Cetaceans**
Other members of Delphinidae; Monodontidae; Plantanistidae*	HF Cetaceans	**MF Cetaceans**	**MF Cetaceans**
Phocoenidae; Iniidae; Kogiidae, Lipotidae; Pontoporiidae; *Cephalorhynchus* spp.; *Lagenorhynchus cruciger*; *Lagenorhynchus australis*	Very High-Frequency (VHF) Cetaceans	**HF Cetaceans**	**HF Cetaceans**
Phocidae	Phocid Carnivores in Water (PCW)	**PW Pinnipeds**	**PW Pinniped**
Otariidae‡	Other Marine Carnivores in Water (OCW)	**OW Pinnipeds**	**OW Pinnipeds**

+ Southall et al. (2019) indicate as more data become available, these species may necessitate their own hearing group (i.e., Very Low-Frequency cetaceans).

^ Southall et al. (2019) indicate as more data become available, these species may necessitate their own hearing group (i.e., Mid-Frequency cetaceans).

* Formerly, NMFS classified all river dolphins were classified as HF cetaceans (based on NMFS 2018 hearing groups) but will now recognize members of the Plantanistidae family as MF cetacean (based on NMFS 2018 hearing groups).

‡ Southall et al. (2019) includes Odobenidae, Ursidae, and Mustelidae within the OCW hearing group. However, these additional families do not include any species under NMFS' jurisdiction. Southall et al. (2019) also includes an additional hearing group, Sirenians, which is not included by NMFS, since none of the species contained within this group fall under NMFS's jurisdiction.

II. ACCOUNTING FOR CUMULATIVE SOUND EXPOSURE

Thresholds expressed in the weighted SEL_{cum} metric account for the level and duration of exposure, both of which are factors that contribute to the potential for a sound source to induce hearing loss. However, despite the advantages associated with the use of this metric, it is recognized that accounting for duration of exposure is complicated when there are moving animals (receivers), as well as potentially moving sources (i.e., difficult to account for dynamic exposure scenarios that change over space and time). Thus, optional Web Calculator tool relies upon two simple methods, one for mobile sources and the other for stationary sources, to account for this weighted cumulative metric. For mobile sources, the optional Web Calculator tool relies upon the concept of "safe distance" from Sivle et al. 2014, while for stationary sources, it relies on deriving a simple maximum 24-h accumulation isopleth.

2.1 MOBILE SOURCES

"Safe distance" is defined as "the distance from the source beyond which a threshold for that metric (SPL_0 or SEL_0) is not exceeded" (Sivle et al. 2014[2]). This method allows one to model a simple moving source and accounts for four main factors:

1) Unweighted source level (action proponent provided)
2) "Pulse"[3] duration and repetition rate (action proponent provided)
3) Transit speed or velocity (action proponent provided)
4) Exposure threshold (NMFS provided from 2018 Revised Technical Guidance)

There are several assumptions with this method, including simple source movement (constant velocity, constant direction); a stationary receiver (no avoidance or attraction to the source) with no vertical or horizontal movement; distance between "pulses" for intermittent sources is consistent, and propagation loss is simple (spherical spreading).

2.2 STATIONARY SOURCES

The derivation of isopleths for stationary sources in the optional Web Calculator tool is by simply accumulating the total duration sound exposure within a 24-hour (h) accumulation period (or less than 24-h, if the period over which the activity occurs is less than 24 hours). This method assumes the receiver (animal) remains stationary during the duration of the activity and is neither attracted nor avoids the source. Recovery between intermittent sounds, regardless of time between sounds, (i.e., all sound within the accumulation period are counted), is not considered. It is possible to specify propagation loss using this methodology.

2.2.1 Assumptions

NMFS understands the optional Web Calculator tool's assumptions for stationary sources are simple. Several important factors determine the likelihood and duration a receiver is expected to be in close proximity to a sound source (i.e., overlap in space and time between the source and receiver). For stationary sources, accumulation time is driven primarily by the characteristics of the receiver (i.e., swim speed and whether transient or resident to the area where the activity is occurring). NMFS recommends a maximum baseline accumulation period of 24-h[4], but acknowledges that there may be specific exposure situations where this accumulation period requires adjustment (e.g., if activity lasts less than 24 h or for situations where receivers are predicted to experience shorter or unusually long exposure durations).

> **NOTE**: The optional Web Calculator tool is flexible and allows the action proponent to specify the duration of sound production within a 24-h period, if appropriate. Thus, if there is enough information to determine that within the duration of sound production in a 24-h period that a receiver (animal) will only be exposed for a portion of that 24-h period, then the actual exposure duration may be used instead. If exposure duration is substituted for sound production duration, then NMFS recommends the action proponent provide information and assumptions used to support this substitution. If the substituted exposure duration varies by species and/or hearing group, it is important to remember to keep track and note which isopleths are appropriate for which hearing groups/species, since the optional Web Calculator tool will calculate isopleths based on the entered duration for all groups. Thus, optional Web Calculator tool may need to be run multiple times to account for this variability among species/hearing groups.

---

[2] The threshold considered by Sivle et al. 2014 was associated with behavioral responses, while NMFS is relying upon this method for assessing PTS onset.

[3] The term "pulse" in the context of the "safe distance" methodology, including the optional Web Calculator tool, is a generic term used to determine isopleths for intermittent sources, and does not imply that these sources are necessarily impulsive.

[4] During review of the Technical Guidance under Presidential Executive Order 13795, Implementing an America-First Offshore Energy Strategy (82 FR 20815; April 28, 2017), public commenters and Federal agencies recommended NMFS convene a working group to investigate means for deriving more realistic accumulation periods, especially for stationary sources. NMFS has convened a working group and is hoping to provide more guidance on this issue in the near future.

2.3 Receiver Considerations

Ultimately, these methods to account for cumulative sound exposure are attempting to predict what exposure an individual animal is likely to receive within a 24-h period. However, capturing the true exposure history of individuals is challenging. For example, the likely cumulative exposure for a resident individual (e.g., pinniped near a haul-out sight) from a passing mobile source is very different from a transient individual (e.g., migrating cetacean) exposed to that same mobile source. Similarly, a transient individual swimming past a stationary source would receive a different cumulative exposure compared to a resident individual inhabiting an area near that same stationary source. Thus, the optional Web Calculator tool's simple methods attempt to capture cumulative sound exposure by focusing on the more predictable characteristics of the sound sources. More sophisticated methods (e.g., Effects of Sound in the Marine Environment workbench (Mountain et al. 2011); Acoustic Integration Model (Frankel et al. 2002), where individual animals are modeled as simulated "animats" capable of accounting for changing sound exposure over space and time via incorporation of species-specific swim speeds and dive profiles, are capable of predicting more realistic[5] exposure levels.

Understanding recovery after sound exposure is also an important consideration. Currently, there is a lack of recovery data for marine mammals, especially for exposure to durations and levels expected under real-world scenarios. Thus, additional marine mammal noise-induced recovery data would be useful. A better understanding of likely exposure scenarios, including the potential for recovery, including how long after noise exposure recovery is likely to occur, could also improve the recommended baseline accumulation period.

2.3.1 Cumulative Metric vs. "Traditional" Root Mean Square Sound Pressure Level Metric

With NMFS' "traditional" thresholds in the root mean square sound pressure level (L_{rms}) metric (e.g., 120/160 dB behavioral harassment thresholds), once a receiver enters the predicted isopleth associate with a particular threshold, it exceeds the threshold and has the potential for PTS onset, in the case of NMFS' former 180 dB and 190 dB L_{rms} thresholds. Thus, duration of exposure was not a consideration (i.e., once a receiver entered the predicted isopleth, it exceeded the threshold no matter whether it stayed there for one second or for 24 hours).

However, with the SEL_{cum} metric, since time (duration of exposure) is inherently included, it makes the situation more complicated. The potential a receiver has for acquiring PTS onset also depends on how long it is exposed and at what level.

III. ACCOUNTING FOR MARINE MAMMAL AUDITORY WEIGHTING FUNCTIONS

Within the optional Web Calculator too (Step 3), action proponents have two options to incorporate the Technical Guidance's marine mammal auditory weighting functions: 1) Weighting Factor Adjustments or 2) Spectrum to override the Weighting Factor Adjustment outputs.

The Weighting Factor Adjustment (WFA) only accounts for marine mammal auditory weighting functions via a single frequency, while relying upon source's spectrum to override the WFA, means that multiple frequencies are considered in the application of marine mammal auditory weighting functions. The choice as to whether a single frequency or multiple frequencies is most appropriate for a sound source, depends primarily on the source's bandwidth[6]:

- Narrowband: a source that produces sounds over a more narrow frequency range, typically with a spectrum having a localized a peak in amplitude
  - Typical sources include: sonar and sonar-like sources
  - Accounting for weighting in terms of a single frequency is most appropriate

[5] However, species-specific swim speeds and dive profiles typically incorporated in "animat" models rely on data from animals under "normal" or non-noise exposed conditions. Thus, how representative these characteristics are of individuals under noise-exposed conditions needs to be considered as well.

[6] Bandwidth (Hz or kHz) is the range of frequencies over which a sound occurs or upper and lower limits of frequency band (ANSI 2005).

- Broadband: a source that produces sound over a broad range of frequencies
  - Typical sources include: seismic airguns, drilling platforms/drill ships, impact and vibratory pile driving hammers.
  - Accounting for weighing in terms of the source spectrum or surrogate spectrum is most appropriate. However, if this is not possible, then a single frequency can be used (See Section 3.1.1.)

NOTE: If the broadband source is a frequency modulated (FM), for example a chirper, and sweeps through a series of frequencies, one at a time, rather than all the frequencies occurring at the same time, which is typical of most other broadband sources (e.g., seismic airguns, impact pile driving hammers, and vibratory pile driving hammers), these FM sources should be treated differently in terms of weighting (See Section 3.2.2).

If the action proponent has no information on how to incorporate weighting for their source (either as a single frequency or multiple frequencies), it is suggested they consider it unweighted (See Section 3.2).

3.1 Weighting Factor Adjustments (Single Frequency)

Weighting factor adjustments (WFAs) are another simple option within the optional Web Calculator tool to help action proponents unable to incorporate the 2018 Revised Technical Guidance's full (i.e., over the entire frequency band associated with the sound source) marine mammal auditory weighting functions. WFAs allow action proponents to rely on the same PTS onset thresholds but accounts for auditory weighting functions by the incorporation of a single frequency.

Within the optional User Spreadsheet tool, WFAs automatically make appropriate adjustments for each marine mammal hearing group based on the frequency chosen. For narrowband sounds, the choice of an appropriate WFA frequency is simple and based on the specified frequency. For broadband sounds, the choice of an appropriate WFA frequency is based on the 95% frequency contour of the particular sound source, which is defined as upper frequency below which 95% of total cumulative energy is contained.

NOTE: If the broadband source is a frequency modulated (FM), for example a chirper, and sweeps through a series of frequencies, one at a time, rather than all the frequencies are occurring at the same time, which is typical of most other broadband sources (e.g., seismic airguns, impact pile driving hammers, and vibratory pile driving hammers), these FM sources should be treated differently in terms of weighting (See Section 3.2.2).

The results from the optional Web Calculator tool will be nearly identical for narrowband sources and more conservative for broadband sources compared to action proponents who can fully implement the 2018 Revised Technical Guidance's auditory weighting functions.

Figure 1 illustrates the concept of WFAs, with using a 1 kHz example (which could be from a 1 kHz narrowband source or a broadband source with a 95% frequency contour at 1 kHz) for all five marine mammal hearing groups. In this Figure the adjustment (-dB) by hearing group is:

- LF cetaceans: -0.06 dB
- MF cetaceans: -29.11 dB
- HF cetaceans: -37.55 dB
- PW pinnipeds: -5.90 dB
- OW pinnipeds: -4.87 dB

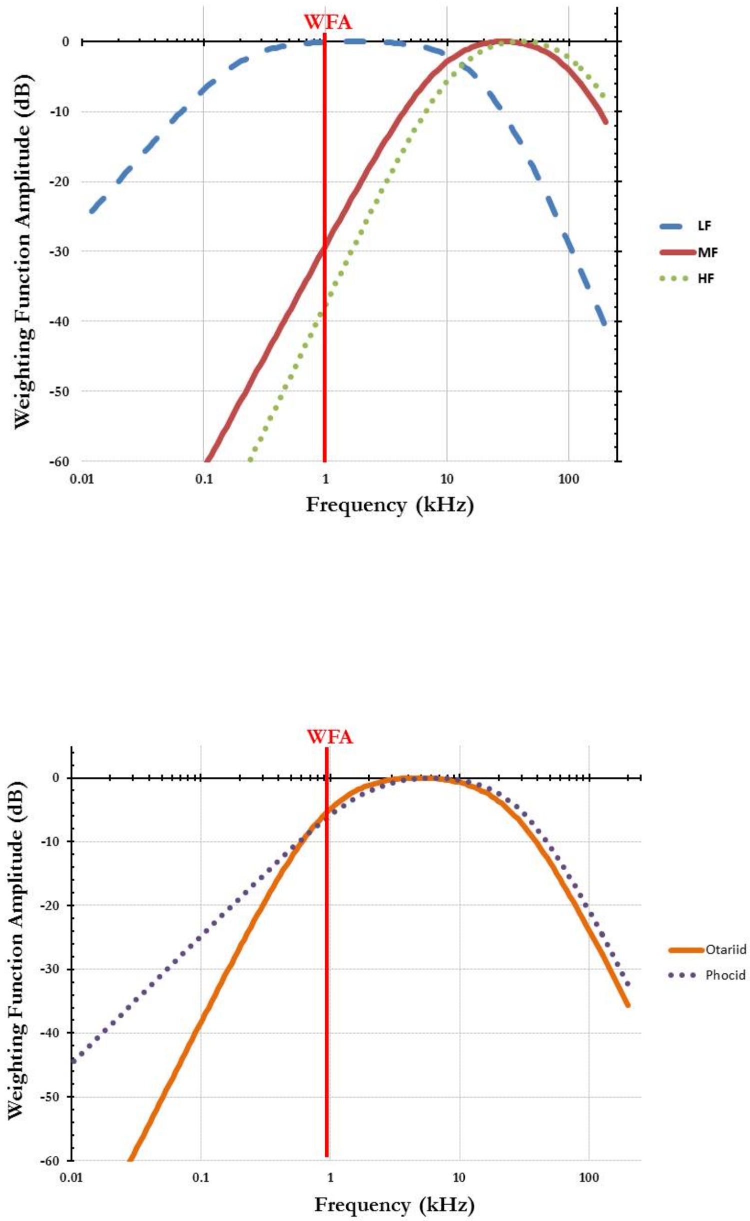


Figure 1: Example illustrating concept of weighting factor adjustment at 1 kHz (red line) with cetacean (top) and pinniped (bottom) auditory weighting functions.

NOTE: The action proponent enters 1 kHz as the WFA in Step 3 of the Calculator Tab of the optional Web Calculator tool. The adjustments (-dB) by marine mammal hearing group are then automatically produced by the tool (i.e., the action proponent does not enter the adjustments (-dB) directly).

As this example illustrates, WFAs always result in zero or a negative dB amplitude. Additionally, the more a sound's frequency is outside a hearing group's most susceptible range (most susceptible range is where the auditory weighting function amplitude equal zero), the more negative WFA that results (i.e., in example above 1 kHz is outside the most susceptible range for MF and HF cetaceans but in the most susceptible range for LF cetaceans; Figure 1, top). Further, the more negative WFA that results will lead to a smaller effect distance (isopleth) compared to a less negative or zero WFA. In other words, considering an identical SEL_{cum} acoustic threshold, a more negative WFA (i.e., source outside most susceptible frequency range) will result in a smaller effect distance (isopleth) compared to one that is less negative or closer to zero (i.e., source inside most susceptible frequency range; Figure 2). In more simplistic terms, the more negative the adjustment, the louder a sound has to be for an animal to experience noise-induced hearing loss.

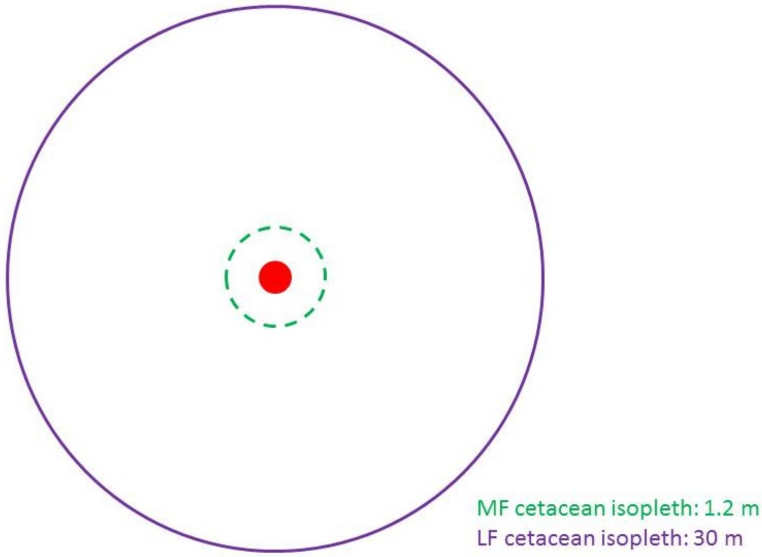


Figure 2: Simple example illustrating concept of weighting factor adjustment on isopleths for LF and MF cetaceans using hypothetical 1 kHz narrowband, intermittent source represented by the red dot (unweighted source level of 200 dB L_{rms}; 1-second ping every 2 minutes for 24 h). For a non-impulsive source, the PTS onset SEL_{cum} threshold for LF cetaceans is 199 dB, while for MF cetaceans is 198 dB. Despite LF cetaceans having a higher PTS onset threshold than MF cetaceans, the isopleth associated with LF cetaceans (30 m solid purple circle) is larger than that for MF cetaceans (1.2 m dashed green circle) based on 1 kHz being within LF cetacean's most susceptible frequency range vs. outside the most susceptible frequency range for MF cetaceans (isopleths not to scale).

In this specific 1 kHz WFA example, there is a larger adjustment for MF and HF cetaceans compared to LF cetaceans. This because for LF cetaceans, 1 kHz is in this hearing group's most susceptible frequency range, while it is outside the most susceptible frequency range for the other two cetacean hearing groups (i.e., MF and HF cetaceans).

The optional Web Calculator tool, specifically Step 3 (Figure 3), allows for a WFA to be provided by an action proponent based on the specific sound source or a default can be used (i.e., single frequency choice). The optional Web Calculator tool provides the adjustment (-dB) associated with the particular WFA provided by marine mammal hearing group (Figure 4). These outputs are calculated automatically within the optional Web Calculator tool, unless an action proponent has the spectrum for their source (i.e., multiple frequency choice).

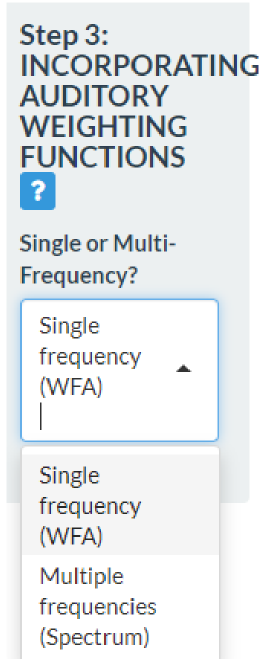


Figure 3: **Screenshot of the ability to incorporate the auditory weighting functions within the optional Web Calculator tool via the single frequency or multiple frequency choices.**

WEIGHTING FUNCTION ADJUSTMENTS (dB)

Table 1: Weighting factor adjustment.

	Low-Frequency cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
Adjustment (-dB)	-0.064	-29.113	-37.545	-5.897	-4.874

Figure 4: **Screenshot of weighting function amplitude associated with 1 kHz WFA by hearing group. Note: These adjustments (-dB) are calculated automatically (i.e., the action proponent does not enter these, unless the action proponent as spectral data for their source, in which they may override the WFA output).**

3.1.1 Choice of Weighting Factor Adjustments for Broadband Sources

There are a couple of options an action proponent determining the appropriate WFA for their broadband sound source: 1) NMFS default WFA or 2) Source-specific WFA. If neither a default nor source-specific WFA can be provided, it is recommended that the source be considered unweighted (See Section 3.2).

NMFS Default WFAs

Action proponents may rely upon a NMFS suggested default for their broadband source, which NMFS acknowledges are likely conservative (Table 2).

Table 2: NMFS suggested default weighting factor adjustments (WFAs) for broadband sources.

Source	WFA	Example Supporting Sources
Seismic airguns	1 kHz	Breitzke et al. 2008; Tashmukhambetov et al. 2008; Tolstoy et al. 2009;
Impact pile driving hammers	2 kHz	Blackwell 2005; Reinhall and Dahl 2011
Vibratory pile driving hammers	2.5 kHz	Blackwell 2005; Dahl et al. 2015a
Drilling equipment	2 kHz	Greene 1987; Blackwell et al. 2004a; Blackwell and Greene 2006

Source-Specific WFAs

Action proponents may rely upon a WFA based off the 95% frequency contour from measurements of their particular source. However, if the action proponent has data on the spectrum associated with their source, they are encouraged to incorporate the full auditory weighting functions, rather than relying upon a simple WFA that only accounts for weighting at one frequency (See Section 3.2).

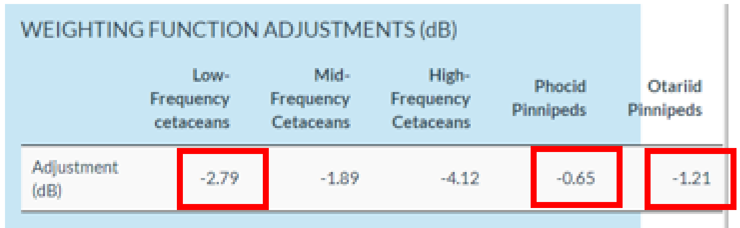
If an action proponent decides to rely upon a source-specific WFA for their broadband source and if the WFA is above 5 kHz for LF cetaceans, above 9 kHz for otariid pinnipeds, or above 11 kHz for phocid pinnipeds, then source should be treated as unweighted (0 dB adjustment; See Section 3.2) (Table 3).

> **NOTE**: An action proponent does not need to be concerned about the applicability of a frequency chosen for a narrowband source (i.e., Table 3 does not apply to narrowband sources; All frequencies are applicable).

Table 3: Applicability of weighting factor adjustments for broadband sources.

Source-Specific WFA	Hearing Group to be Treated as Unweighted
Above 5 kHz	LF Cetaceans
Above 9 kHz	LF Cetaceans and Otariid Pinnipeds
Above 11 kHz	LF Cetaceans, Otariid Pinnipeds, and Phocid Pinnipeds

> **FICTITIOUS EXAMPLE A**: If a broadband source had a source-specific WFA of 12 kHz, then the action proponent would start by enter 12 kHz for the Single Frequency (WFA) option in Step 3 and would note the weighting function amplitude (-dB) produced for MF and HF cetaceans, while all other hearing groups would need to be treated as unweighted (i.e., action proponent may not rely upon weighting function amplitude (-dB) produced for LF cetaceans, PW pinnipeds, or OW pinnipeds) (Figure 5).



WEIGHTING FUNCTION ADJUSTMENTS (dB)

	Low-Frequency cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
Adjustment (dB)	-2.79	-1.89	-4.12	-0.65	-1.21

Figure 5: Example of weighting function adjustments (-dB) produced by entering 12 kHz as the Single Frequency (WFA) option for a broadband source in Step 3 of the optional Web Calculator tool. NOTE: 12 kHz is not an applicable frequency for Low-Frequency Cetaceans, Phocid Pinnipeds, or Otariid Pinnipeds (based on Table 3). Thus, the weighting function amplitude produced for these three hearing groups cannot be used, as indicated by the red boxes (i.e., weighting function amplitude produced can only be used for Mid-Frequency and High-Frequency Cetaceans).

To incorporate the Technical Guidance's weighting functions, the action proponent would need to go back to Step 3 and choose the Multiple Frequencies (Spectrum) option. From there, they would enter the adjustment (-dB) produced for MF- and HF-cetaceans and then enter zero for all other hearing groups to make these groups unweighted (Figure 6).

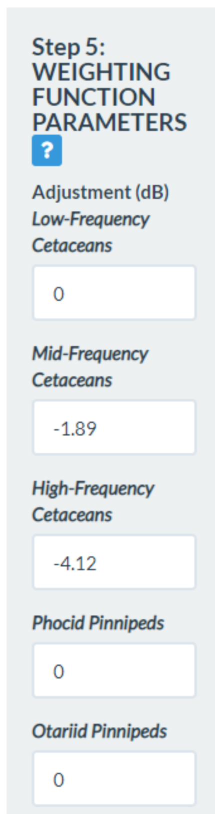


Figure 6: Example of manually entering weighting function adjustments (-dB) for each hearing groups (i.e., using weighting function adjustment produced for 12 kHz for Mid- and High-Frequency Cetaceans and entering zero for all other hearing groups).

FICTITIOUS EXAMPLE B: If the source-specific WFA was 7 kHz, only LF cetaceans would have to be considered unweighted (i.e., otariid and phocid pinnipeds would not have to be considered unweighted). Thus, the action proponent would start by enter 7 kHz for the Single Frequency (WFA) option in Step 3 and would note the weighting function amplitude (-dB) produced for all hearing groups except LF cetaceans. LF cetaceans would need to be treated as unweighted (i.e., action proponent may not rely upon weighting function amplitude (-dB) produced for LF cetaceans) (Figure 7).

Weighting Function Adjustments (-dB)

	Low-Frequency cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
Adjustment (dB)	-0.98	-5.42	-9.38	-0.02	-0.17

Figure 7: **Example of weighting function adjustments (-dB) produced by entering 7 kHz as the Single Frequency (WFA) option for a broadband source in Step 3 of the optional Web Calculator tool. NOTE: 7 kHz is not an applicable frequency for Low-Frequency Cetaceans (based on Table 3). Thus, the weighting function amplitude produced for this hearing groups cannot be used, as indicated by the red box (i.e., weighting function amplitude produced can only be used for Mid-Frequency, High-Frequency Cetaceans, Phocid Pinnipeds, and Otariid Pinnipeds).**

To incorporate the Technical Guidance's weighting functions, the action proponent would need to go back to Step 3 and choose the Multiple Frequencies (Spectrum) option. From there, they would enter the adjustment (-dB) produced for all hearing groups, except LF cetaceans, and then enter zero for LF cetaceans to make this group unweighted (Figure 8).

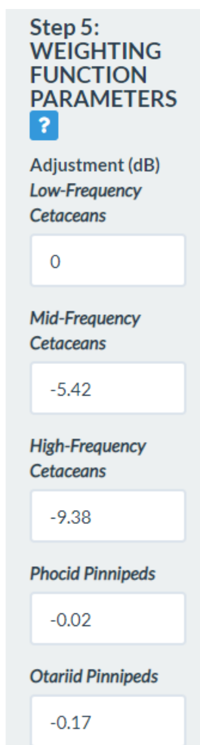


Figure 8: **Example of manually entering weighting function adjustments (-dB) for each hearing groups (i.e., using weighting function adjustment produced for 7 kHz for all hearing groups, except Low-Frequency Cetaceans and entering zero for Low-Frequency Cetaceans).**

3.2 SPECTRUM (MULTIPLE FREQUENCIES)

An action proponent need not rely upon WFAs if: 1) The action proponent has no information on an appropriate WFA value for their source and no default value is available (i.e., Adjustment (-dB) is set to zero, so source is unweighted), 2) The action proponent has specific information on the spectrum associated with their source, or 3) The action proponent chooses to rely on a default spectrum provided by NMFS (see Section 4.2 for more information on option 3).

If an action proponent has data or measurements depicting the spectrum of their sound source, they may incorporate these directly within the optional Web Calculator tool via Step 3 the Multiple Frequencies (Spectrum) option (Figure 9).

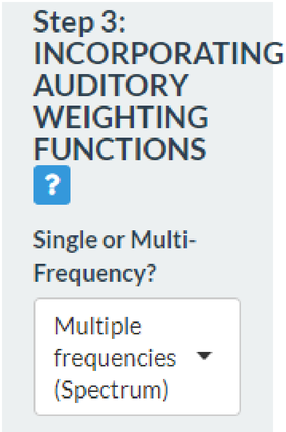


Figure 9: Screenshot of Step 3, where action proponent is given the ability to incorporate the sound source spectrum within the optional Web Calculator tool.

By including a source's entire spectrum, this will allow an action proponent to incorporate the 2018 Revised Technical Guidance's marine mammal auditory weighting functions over the entire broadband frequency range of the source, rather than just for one frequency via the WFA. As a result, optional Web Calculator tool's WFA with a sound sources' spectrum will result in more realistic (i.e., likely smaller) isopleths (i.e., NMFS' preference is that spectrum data be use for broadband sources, when possible, compared to the simple WFA). However, the action proponent must provide clear evidence to NMFS of how the spectrum data were derived and used. NMFS is currently evaluating whether surrogate spectrum are available and applicable for particular sound sources, if an applicant does not have data of their own to use.

Spectral levels, depending on the sound source, are typically depicted as power spectral density (PSD) (1 Hz bands) or one-third octaves (OTO) (base 10) (Figure 10[7]). NMFS recommends that action proponents provide spectra as a power spectral density, which provides the most detail about the source in terms of frequency (e.g., by 1 Hz bands). However, we recognize that this may not be appropriate or feasible for all sound sources. In those situations, NMFS recommends that action proponents relying upon OTO data apply the auditory weighting functions via the center frequency of each applicable OTO for each hearing group (Table 4; ANSI 2009).

[7] For general information on spectral analysis and relationship between PSD and OTO levels, see Richardson et al. 1995.

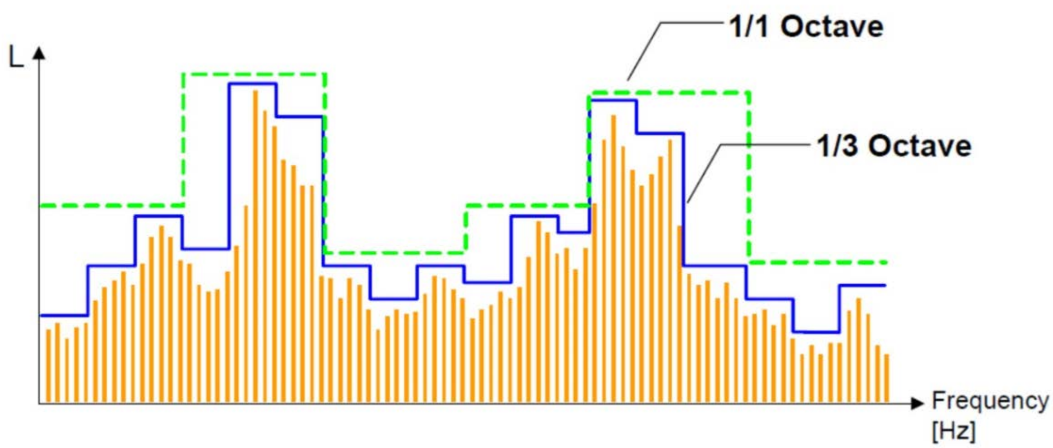


Figure 10: **Illustration comparing generic spectral levels presented as octaves (dashed line), one-third octave (solid line), and power spectral density (vertical bars) for a generic sound source.**

Table 4: **Auditory weighting functions based on one-third octave (OTO) bands (ANSI 2009).***

Center (Hz)	LF Cetaceans	MF Cetaceans	HF Cetaceans	Phocids Underwater	Otariids Underwater
8	**-27.84**	-96.12	-112.98	-46.76	-82.16
10	**-25.90**	-93.02	-109.49	-44.83	-78.29
12.5	**-23.97**	-89.92	-106.00	-42.89	-74.41
16	**-21.84**	-86.49	-102.14	-40.74	-70.12
20	**-19.91**	-83.39	-98.65	-38.80	-66.25
25	**-18.00**	-80.29	-95.16	-36.87	-62.37
31.5	**-16.03**	-77.08	-91.55	-34.86	-58.36
40	**-14.02**	-73.76	-87.82	-32.79	-54.22
50	**-12.17**	-70.66	-84.33	**-30.85**	-50.35
63	**-10.31**	-67.44	-80.71	**-28.84**	**-46.35**
80	**-8.47**	-64.13	-76.98	**-26.77**	**-42.22**
100	**-6.86**	-61.02	-73.49	**-24.84**	**-38.38**
125	**-5.38**	-57.92	-70.00	**-22.91**	**-34.56**
160	**-3.96**	**-54.49**	-66.14	**-20.77**	**-30.37**
200	**-2.88**	**-51.39**	-62.66	**-18.85**	**-26.63**
250	**-2.02**	**-48.30**	**-59.17**	**-16.94**	**-22.96**
315	**-1.34**	**-45.09**	**-55.56**	**-14.98**	**-19.28**
400	**-0.84**	**-41.77**	**-51.83**	**-12.97**	**-15.65**
500	**-0.52**	**-38.68**	**-48.34**	**-11.14**	**-12.49**
630	**-0.30**	**-35.48**	**-44.74**	**-9.30**	**-9.54**
800	**-0.15**	**-32.18**	**-41.01**	**-7.48**	**-6.90**
1000	**-0.06**	**-29.11**	**-37.55**	**-5.90**	**-4.87**

Center (Hz)	LF Cetaceans	MF Cetaceans	HF Cetaceans	Phocids Underwater	Otariids Underwater
1250	**-0.02**	**-26.06**	**-34.09**	**-4.46**	**-3.27**
1600	**0.00**	**-22.72**	**-30.28**	**-3.10**	**-1.97**
2000	**-0.01**	**-19.74**	**-26.87**	**-2.08**	**-1.15**
2500	**-0.05**	**-16.83**	**-23.50**	**-1.29**	**-0.60**
3150	**-0.12**	**-13.92**	**-20.08**	**-0.69**	**-0.24**
4000	**-0.26**	**-11.07**	**-16.65**	**-0.29**	**-0.05**
5000	**-0.46**	**-8.62**	**-13.59**	**-0.07**	**0.00**
6300	**-0.78**	**-6.35**	**-10.63**	**0.00**	**-0.09**
8000	**-1.29**	**-4.36**	**-7.88**	**-0.09**	**-0.33**
10000	**-2.00**	**-2.86**	**-5.66**	**-0.32**	**-0.73**
12500	**-2.99**	**-1.71**	**-3.81**	**-0.74**	**-1.35**
16000	**-4.53**	**-0.82**	**-2.24**	**-1.49**	**-2.37**
20000	**-6.35**	**-0.31**	**-1.22**	**-2.48**	**-3.68**

* Bold text indicates OTO bands within generalized hearing range of each marine mammal group.

As an example illustrating the use of a source spectrum (OTO), Figure 118 in Appendix D of the Final Environmental Impact Statement for Gulf of Mexico OCS Proposed Geological and Geophysical Activities (BOEM 2017) provides a generic spectrum for an 8000 in^3 airgun array from 10 Hz to 5 kHz (Figure 11).

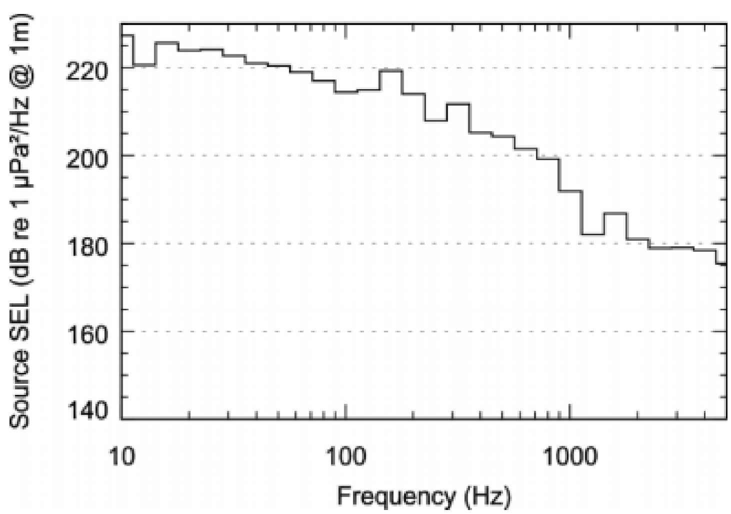


Figure 11: Maximum one-third octave band unweighted source level in the horizontal plane for a generic 8000 in^3 seismic array (BOEM 2017).

With the source spectrum, the action proponent can compare the unweighted source level to the weighted source level by hearing group. The weighting adjustment (-dB) is the difference between the weighted and unweighted source level (e.g., if LF cetacean weighted source level was 227.3 dB and the unweighted source level was 240 dB, then the weighting adjustment would be -12.7 dB). This adjustment can directly be incorporated in the optional Web Calculator tool. If an action proponent needs further guidance on how to do this, NMFS has an additional spreadsheet to help with this computation.

Table 5 provides a comparison of the -dB adjustment between using the BOEM 2017 spectrum (10 Hz to 5 kHz) and the default WFA. As NMFS has stated previously, the more factors an action proponent can incorporate in their modeling, the more realistic results expected.

Table 5: Seismic airgun weighting using a broadband spectrum vs. default, single frequency WFA.

Weighting Adjustment (-dB)	LF cetacean	MF cetacean	HF cetacean	PW pinniped	OW pinniped
Default WFA for seismic array (1 kHz)	-0.06 dB	-29.11 dB	-37.55 dB	-5.90 dB	-4.87 dB
Seismic array spectrum (BOEM 2017)*	-12.7 dB	-57.4 dB	-65.7 dB	-28.7 dB	-33.6 dB

* BOEM 2017 spectrum was digitized using WebPlotDigitizer. In this example, the adjustments from the seismic arrays spectrum could be used directly optional Web Calculator tool's default WFA for seismic.

3.2.1 Spectral Considerations for Broadband Sources

NMFS understands and acknowledges that the frequency spectra of a source changes dramatically over propagation loss conditions. NMFS recommends action proponents consider the spectrum in terms of what is most representative for the impacts expected, which is expected to be at shorter ranges associated with the 2018 Revised Technical Guidance's PTS onset thresholds.

3.2.2 Special Consideration: Frequency Modulated Broadband Sources (e.g. chirpers)

Frequency modulated (FM) sources that sweep through a range of frequencies, one or few at a time, have the same spectral content of a broadband sound where all the frequencies are occurring simultaneously. However, for the purposes of the optional User Spreadsheet tool, evaluating FM sources the same as other broadband sources is not appropriate (e.g., not appropriate to choose a WFA or directly use the spectrum for purposes of incorporating the Technical Guidance's auditory weighting functions.

Instead, NMFS recommends action proponents treat FM sources as narrowband for the purposes of incorporating the Technical Guidance's auditory weighting functions. This means an action proponent will need to evaluate multiple frequencies to determine the most appropriate isopleth by marine mammal hearing group (i.e., NMFS recommends the action proponent choose the "Singe Frequency (WFA)" option in Step 3 and evaluate the isopleths produced using the lowest and highest frequencies produced and relying upon which frequency produces the largest isopleth for each hearing group).

Additionally, if the FM source produces sound in or around a hearing group's most susceptible frequency range (Table 6), then the action proponent should treat the source as unweighted for that hearing group and use the unweighted isopleth produced by the optional User Spreadsheet tool (See Section 3.2).

Table 6: Marine mammal hearing group's most susceptible frequency range.

Marine Mammal Hearing Group	Most Susceptible Frequency
Low-frequency (LF) cetaceans	0.5 to 5 kHz
Mid-frequency (MF) cetaceans	18 to 47 kHz
High-frequency (HF) cetaceans	25 to 62 kHz
Phocid (PW) pinnipeds	3.5 to 11 kHz
Otariid (OW) pinnipeds	2.5 to 9 kHz

IV. DEFAULT VALUES

NMFS understands that the optional Web Calculator tool requires additional source parameter information that has not been previously required. For those action proponents unable to provide key pieces of information, NMFS has created appropriate defaults. NMFS acknowledges that suggested default values are likely conservative, which is the intent when activity-specific information is unavailable, in order to cover potential variability.

> **NOTE:** Defaults are meant to be conservative in order to encompass the broad potential range of values associated with an activity or sound source (e.g., for pile driving variation could result from water depth associated with activity, sediment characteristics, pile diameter, pile material, etc.). Thus, an action proponent is always encouraged to use activity-specific information, if available, as a substitute for using NMFS' recommended default values, as this activity-specific information will provide a more realistic representation of the isopleths associated with that activity (Figure 12).

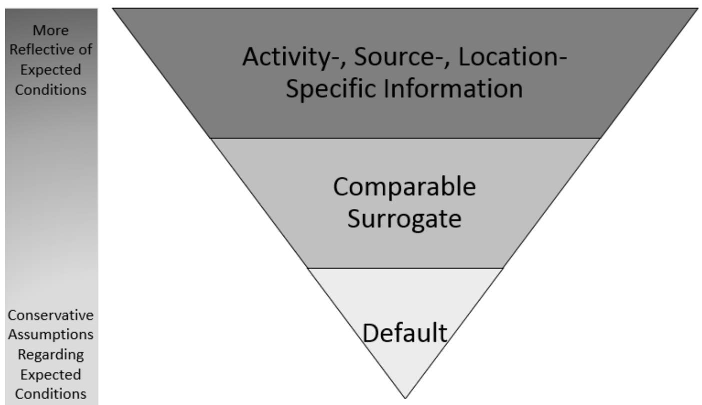


Figure 12: Illustration of data hierarchy and impacts on portraying expected conditions

4.1 WEIGHTING FACTOR ADJUSTMENT SUGGESTED DEFAULTS

For example, NMFS provides suggested default WFAs for common broadband sources (Table 7).

Table 7: NMFS suggested default WFA for common* broadband sources.

Source	Default WFA	References supporting default WFA
Seismic airguns	1 kHz	Breitzke et al. 2008; Tashmukhambetov et al. 2008; Tolstoy et al. 2009
Impact pile driving hammers	2 kHz	Blackwell 2005; Reinhall and Dahl 2011
Vibratory pile driving hammers	2.5 kHz	Blackwell 2005; Dahl et al. 2015a
Drilling equipment	2 kHz	Greene 1987; Blackwell et al. 2004a; Blackwell and Greene 2006

4.2 SOURCE LEVEL AND PULSE DURATION

If source level information is unavailable, NMFS recommends the action proponent find an appropriately similar surrogate source. If a surrogate source is used, NMFS requests the action proponent provide information on why it is an appropriate substitute.

If an action proponent only has unweighted source level information based on the L_{rms} metric, then it is necessary to determine the pulse duration or rely upon an appropriate default value. NMFS' recently completed an analysis to provide a default value (100 milliseconds, msec) for both the impact pile driving hammers and seismic airgun sources provided in Appendix B (impact pile driving) and Appendix C (seismic airguns).

NOTE: If the action proponent has unweighted source level information expressed in the single strike/shot SEL metric, then determining the pulse duration is not necessary. Many of the sound source tabs provide a choice between two methods (i.e., one relying on L_{rms} source levels or one relying upon single strike/shot SEL source levels). NMFS advises action proponents to rely on the method using the single strike/shot SEL source level, so needing to determine the pulse duration (or appropriate default) is unnecessary.

Cumulative sound exposure can be computed using a simple equation, assuming a constant received sound pressure level (SPL) that does not change over space and time (Equation E1.; e.g., Urick 1983; ANSI 1986; Madsen 2005):

$$SEL_{cum} = L_{rms} + 10 \log_{10} (\text{duration of exposure, expressed in seconds}) \text{ dB} \qquad \textbf{Equation 1}$$

USER TIP: Sources producing ping/strike/pulse/shot less than a second in duration have a larger L_{rms} value compared to SEL value, while sources producing ping/strike/pulse/shot greater than a second have a larger SEL value compared L_{rms} value. If the ping/strike/pulse/shot is exactly 1 second, then the L_{rms} and SEL values are equal.

For example, a source producing a 100 msec pulse has a SEL value that is 10 dB less than its L_{rms} value.

4.3 Propagation/Transmission Loss[8] Defaults

NMFS also acknowledges that the optional User Spreadsheet tool takes a simple approach to propagation loss. Sound propagation/transmission loss through the environment can be complicated and depend on a multitude of factors, which can vary temporally and spatially (see reviews in Urick 1979, 1983; Forest 1994; Richardson et al. 1995). Many of these factors that affect sound propagation/transmission loss can be extremely site-specific. This is particularly the case for shallow water (Richardson et al. 1995). Sound propagation/transmission loss can be measured directly or modeled. The more site-specific data available, the greater chance of accurately predicting sound propagation/transmission loss through the environment via modeling and ultimately the level at the receiver. Thus, NMFS recommends that when site-specific information on propagation/transmission loss is available, it be used. For coastal activities, such as pile driving, if area-specific information on propagation/transmission loss is not available, NMFS typically recommends practical spreading[9] (TL=15 log R2/R1) (e.g., Stadler and Woodbury 2009; Caltrans 2015).

NOTE: The distinction between "shallow" and "deep" water is typically based the ratio of acoustic wavelength to water depth. "Deep" water considered > 100 times the acoustic wavelength and where there is little to no interaction between the sound with the bottom and spherical spreading (20 Log R) is appropriate. "Shallow" water propagation loss is dominated by multiple surface and bottom reflections (Urick 1983; Richardson et al. 1995).

The optional User Spreadsheet tool's "safe distance" methodology for mobile sources assumes propagation loss (default) is spherical spreading (20 Log R).

V. PEAK SOUND PRESSURE LEVEL THRESHOLDS

The PK metric (for impulsive sources) is included in the optional Web Calculator tool (Version 1.0). When evaluating impulsive sources that have dual metric thresholds (i.e., SEL_{cum} and PK), an action proponent

[8] Note: Transmission loss is conceptually different from propagation loss (i.e., propagation loss is associated with the source level, while transmission loss is associated with a measurement at a specified distance) (ISO 2017).

[9] R1 is the range for a close range measurement, typically 10 m from the pile source, and R2 is a longer range at which an underwater sound metric such a peak pressure, or sound exposure level is estimated (Dahl et al. 2012). Additionally NMFS is aware that other TL models may be more appropriate for pile driving (e.g., Reinhall and Dahl 2011; Zampolli et al. 2013; Schecklman et al. 2015; Lippert et al. 2018) but until various factors (e.g., decay factor associated with Lippert et al. 2018) can be derived/estimated for all pile types and locations, a simplified model is recommended.

relies upon whichever metric yields the largest isopleth for a particular marine mammal hearing group. The PK thresholds are unweighted/flat-weighted within the generalized hearing range of marine mammals (i.e., 7 Hz to 160 kHz).

> **NOTE**: If an action proponent get output "NA" instead of a numerical isopleth associated with the PTS PK isopleth, this means the PK source level is less than or equal to the threshold for the particular marine mammal hearing group.
>
> For impact pile driving hammers, true source levels (i.e., levels reference to 1 m from the source) are typically not provided. Instead for these sources, sound levels (L_{rms}, Single Strike SEL, or PK) are typically referenced 10 m from the source. Thus, for these sources, the action proponent is also asked to specify the distance of the sound level measurement.

VI. OPTIONAL WEB CALCULATOR TOOL

The optional Web Calculator tool consists of four tabs (i.e., a Calculator tab and three informational tabs (Figure 13) :

- Calculator Tab: Home Tab where action proponent enters project and source information to compute threshold isopleths (meters)

- Introduction Tab: Tab that provides a general introduction to the optional Web Calculator tool

- Weighting Factor Adjustment (WFA) Tab: Tab that provides the default suggested WFAs for common broadband sources.
    - WFAs consider marine mammal auditory weighting functions by focusing on a single frequency for those who cannot fully apply auditory weighting functions associated with the SEL_{cum} metric thresholds.

- Glossary and Literature Cited Tab: Tab that provides a list of abbreviations and glossary terms found in the optional Web Calculator Tool. It also provides a list of literature cited.

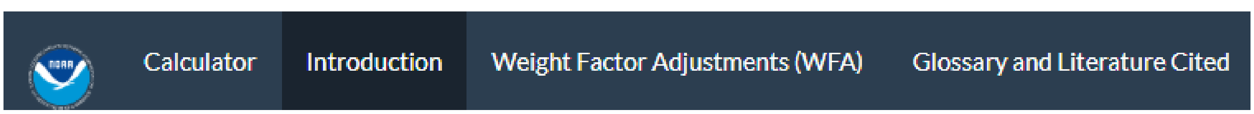


Figure 13: Screenshot illustrating ribbon of optional Web Calculator tool's four tabs.

> **NOTE**: The optional Web Calculator tool will "**time out**" after inactivity. Action proponents are advised to save their work (i.e., inputs and outputs) by using the gray "Generate Report" button at the bottom of the Threshold Isopleths Results Window (Figure 14).

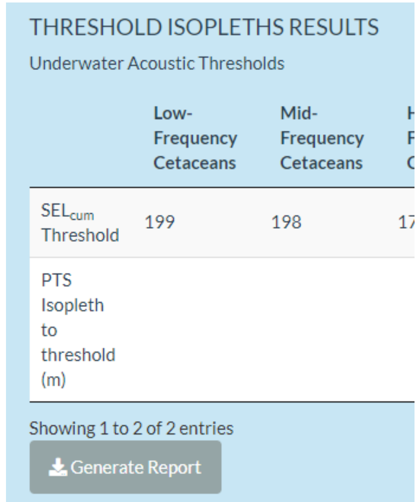


Figure 14: Screenshot of gray "Generate Report" button at the bottom of the Threshold Isopleths Results window.

6.1 INTRODUCTION TAB

NMFS recommends an action proponent start by reading the information provided within the Introduction tab (Figure 15), which provides introductory information on the optional Web Calculator, including a disclaimer and note, as well as a link to the 2018 Revised Technical Guidance.

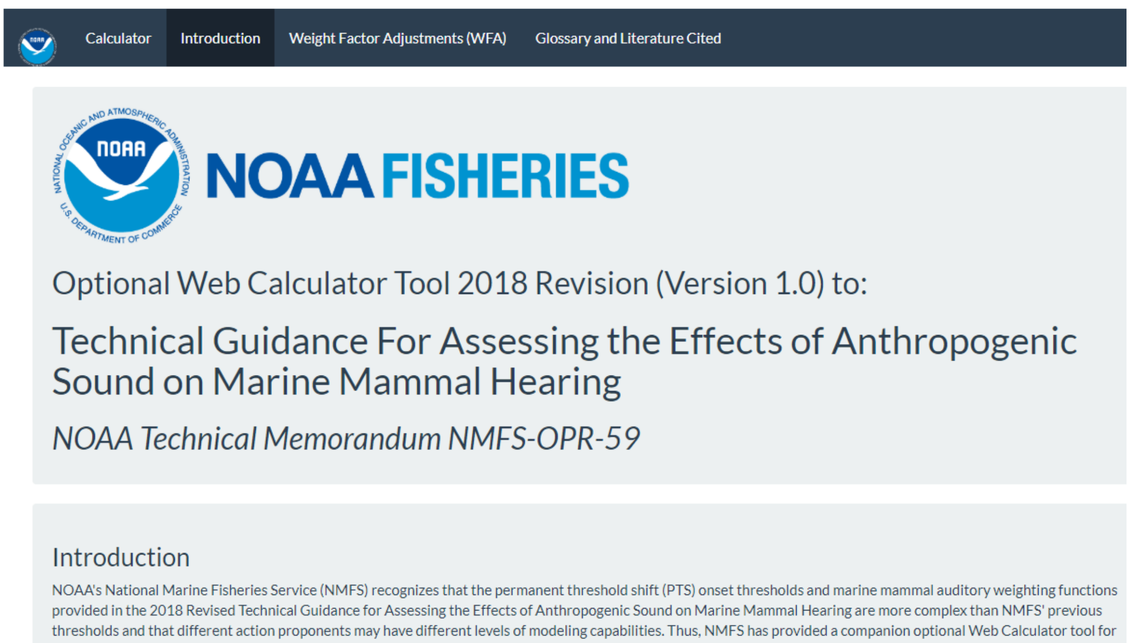


Figure 15: Screenshot of Introduction tab.

6.2 CALCULATOR TAB (HOME TAB)

The Calculator tab is the tab that where an action proponent provides information about their source and resultant isopleths are produced. Action proponents should fill out information about their project and sound source in the order specified via Steps 1 through 5.

NOTE: The optional Web Calculator tool will "**time out**" after inactivity. Action proponents are advised to save their work (i.e., inputs and outputs) by using the gray "Generate Report" button at the bottom of the Threshold Isopleths Results Window (Figure 16).

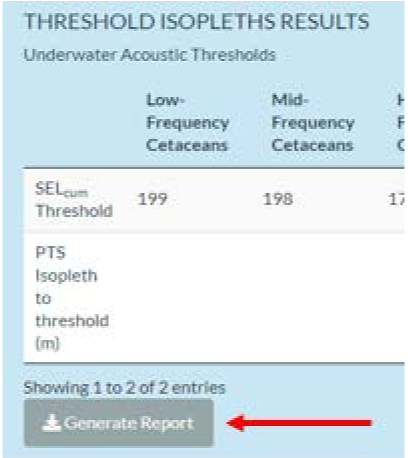


Figure 16: Screenshot of gray "Generate Report" button at the bottom of the Threshold Isopleths Results window (as indicated by the red arrow).

NOTE: Within the Calculator Tab, there are numerous informational buttons denoted by a blue question mark (Figure 17) that provide additional information about that Window.

Figure 17: Screenshot of informational button (blue question mark as indicated by the red arrow) found in Calculator Tab.

NOTE: In Steps 4 and 5, missing or incorrect values will be highlighted orange (Figure 18). Once an acceptable value has been entered, the box will no longer be highlighted.

Figure 18: Screenshot illustrating orange highlighted values in Steps 4 and 5, indicating incorrect or missing values. Once a correct value has been entered, these boxes will no longer be highlighted orange.

6.2.1 Step 1

This Step is where the action proponent provides basic project information (Figure 19), such as:

- Project Title: Project type and location.
- Project Contact: Person responsible for completing the optional Web Calculator tool.
- Project/Source Information (Including assumptions): Basic information about the activity as well as any assumptions included in when completing the optional Web Calculator tool.

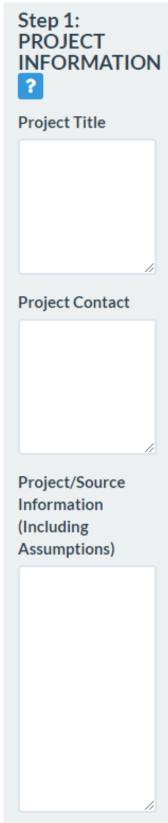


Figure 19: Screenshot of Step 1 to provide project information.

6.2.2 Step 2

This Step provides the action proponent the ability to choose both their sound source and sound source metric for calculating cumulative sound exposure (Figure 20).

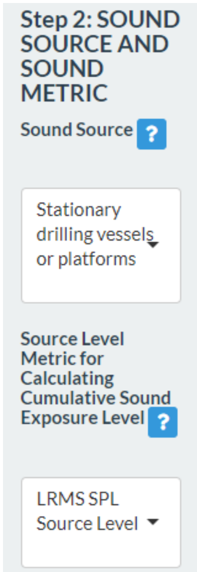


Figure 20: Screenshot of Step 2 to choose sound source/source category and source level metric.

6.2.2.1 Sound Source or Source Category

An action proponent may choose either the particular sound source (e.g., impact pile driver, mobile seismic airguns) of the activity being analyzed or a more generic sound source category (non-impulsive vs. impulsive; mobile vs. stationary; continuous vs. intermittent).

> **NOTE**: An action proponent may access the generic sound source category by choosing "Other" in the Sound Source menu (Figure 21).

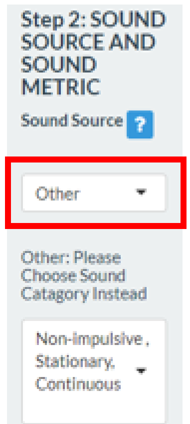


Figure 21: Screenshot illustrating option to choose the sound source category via "Other" option (as indicated by the red box) in Step 2.

Sound Source

An action proponent can choose one of eight Sound Sources (Figure 22):

1. Impact pile drivers (Corresponds to Tab E.1 (Evergreen) in User Spreadsheet tool)
2. Vibratory pile driving divers (Corresponds to Tab A.1 (Brick) in User Spreadsheet tool)
3. Mobile seismic airguns
4. Stationary seismic airguns (e.g., Vertical seismic profiling)
5. Stationary drilling vessels or platforms
6. Stationary sonar or sonar-like sources
7. Mobile sonar or sonar-like sources
8. Other The action proponent would choose this option if the particular sound source associated with their activity is not on the list of Sound Sources. By choosing this option, the action proponent my instead choose the source category that best describes their sound source (Figure 21).

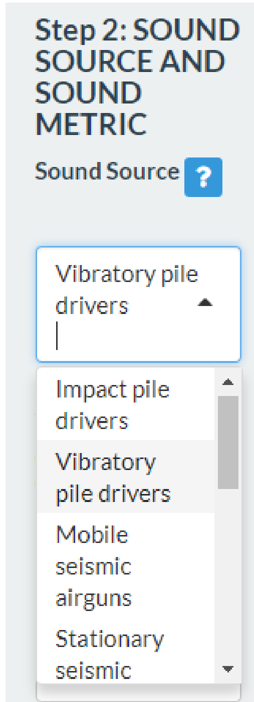


Figure 22: Screenshot of dropdown menu where action proponent can choose the sound source.

If the action proponent cannot find their particular sound source from the above list, NMFS recommends the action proponent decide which Sound Source Category most appropriately represents their source via choosing the "Other" option (Figure 21).

> **NOTE**: NMFS considers the use of the optional Web Calculator tool as overly simplistic for the consideration of underwater detonations. Please consult NMFS as to how most appropriately evaluate underwater detonations in the context of the Technical Guidance.

Sound Source Category

An action proponent can choose one of six Sound Source Categories (Figure 23):

1. Non-impulsive, Stationary, Continuous: Corresponds to Tab A (Red) in the optional User Spreadsheet tool.

2. Non-impulsive, Stationary, Intermittent: Corresponds to Tab B (Yellow) in the optional User Spreadsheet tool.

3. Non-impulsive, Mobile, Continuous: Corresponds to Tab C (Blue) in the optional User Spreadsheet tool.

4. Non-impulsive, Mobile, Intermittent: Corresponds to Tab D (Orange) in the optional User Spreadsheet tool.

5. Impulsive, Stationary: Corresponds to Tab E (Green) in the optional User Spreadsheet tool.

   NOTE: NMFS considers the use of the optional Web Calculator tool as overly simplistic for the consideration of underwater detonations. Please consult NMFS as to how most appropriately evaluate underwater detonations in the context of the Technical Guidance.

6. Impulsive, Mobile: Corresponds to Tab F (Purple) in the optional User Spreadsheet tool.

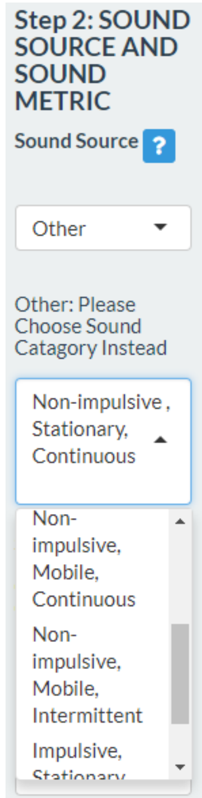


Figure 23: Screenshot of dropdown menu to choose the sound source category via "Other" option in Step 2.

NOTE: NMFS created tabs to cover all current and future sound sources. However, this does not mean **all** sources have equal potential to cause noise-induced hearing loss or exceed the 2018 Revised Technical Guidance's PTS onset thresholds. For example, some tabs are likely used more often compared to others, while other tabs are available if needed for future use.

To decide within which sound source category a source fits, NMFS offers the following guidance:

Deciding whether a sound source is non-impulsive or impulsive:

- <u>Non-impulsive sound</u>: Sound sources that produce sounds that can be broadband, narrowband or tonal, brief or prolonged, continuous or intermittent) and typically do not have a high peak sound pressure with rapid rise time that impulsive sounds do (ANSI 1995; NIOSH 1998).

  Examples of non-impulsive sound sources include marine vessels, machinery operations/construction (e.g., drilling), certain active sonar (e.g. tactical, navigational, and scientific), and vibratory pile driving hammers.

NOTE: The optional Web Calculator tool treats all sound sources as omnidirectional (i.e., this may not be appropriate for sources that are highly directional and/or have narrow beam patterns).

- <u>Impulsive sound</u>: Sound sources that produce sounds that are typically transient, brief (less than 1 second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay (ANSI 1986; NIOSH 1998; ANSI 2005). They can occur in repetition or as a single event. Examples of impulsive sound sources include explosives, seismic airguns, and impact pile driving hammers.

NOTE: The term "impulsive" in this document relates specifically to noise-induced hearing loss and specifies the physical characteristics of an impulsive sound source, which likely gives them a higher potential to cause auditory TTS/PTS. This definition captures how these sound types may be more likely to affect auditory physiology and is not meant to reflect categorizations associated with behavioral disturbance.

Deciding whether a sound source is stationary or mobile:

- Stationary: A source that remains in a location during sound production (e.g., impact and vibratory pile driving).

- Mobile: A source that moves through the water or is attached to a vessel that moves through the water during sound production (e.g., sonar towed by a vessel and airguns towed by a vessel).

Deciding whether a sound source is continuous or intermittent

- Continuous sound: A sound whose sound pressure level remains above ambient sound during the observation period (ANSI 2005).

- Intermittent sound: Interrupted levels of low or no sound (NIOSH 1998) or bursts of sounds separated by silent periods (Richardson and Malme 1993). Typically, intermittent sounds have a more regular (predictable) pattern of bursts of sounds and silent periods (i.e., duty cycle).

NOTE: Within the optional Web Calculator tool, a key distinction between continuous and intermittent sound sources is that intermittent sounds have a more regular (predictable) pattern of bursts of sounds and silent periods (i.e., duty cycle), which continuous sounds do not.

Source Level Metric
Depending on the source, there may be multiple options as far as source level. For impulsive sources, the peak sound pressure level (PK) metric source level is also required, since impulsive sources have dual thresholds (Figure 24).

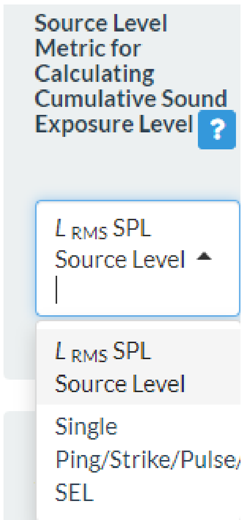


Figure 24: Screenshot of dropdown menu where action proponent can choose source level metric.

NOTE: When relying upon the optional Web Calculator tool, action proponents are to provide unweighted source levels.

For impulsive sound sources, the peak sound pressure level source level is also needed later in Step 4.

For vibratory pile driving hammers and impact pile driving hammers, true source levels (i.e., levels reference to 1 m from the source) are typically not provided. Instead for these sources, sound levels (L_{rms}, SEL_{ss}, or PK) are typically referenced 10 m from the source. Thus, for these sources, the action proponent is also asked to specify the distance of the sound level measurement (Step 4).

L_{rms} Source Level

This source level is available for all source types and is defined as the square root of the average of the square of the pressure of the sound signal over a given duration (ANSI 2005).

If the source level provided includes an attenuation methods (e.g., bubble curtain), please note that in the Project/Source Information cell in Step 1 (i.e., attenuated source level via *xx* method).

Single Ping/Strike/Pulse/Shot Equivalent Source Level

For intermittent sources, an action proponent also has the option to provide source level in terms of single strike/ping/pulse/shot equivalent.

NOTE: This single ping/strike/pulse/shot SEL metric represents the sound exposure of a single ping/strike/pulse/shot and is not cumulative.

If the action proponent has unweighted source level information expressed in the SEL metric, then determining the pulse duration is not necessary. Many of the sound source categories provide a choice between two methods (i.e., one relying on L_{rms} source levels or one relying upon SEL source levels). NMFS advises action proponents to rely on the method using the SEL source level, so needing to determine the pulse duration (or appropriate default) is not necessary.

6.2.3 Step 3

This Step allows the action proponent to incorporate the 2018 Revised Technical Guidance's marine mammal auditory weighting functions (Figure 25).

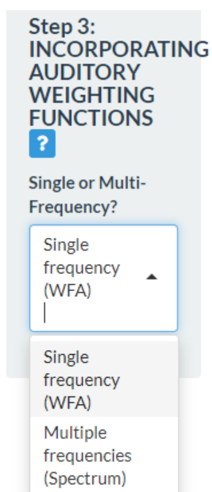


Figure 25: Screenshot of Step 3 used to incorporate marine mammal auditory weighting functions.

NOTE for FM Sources (e.g., chirpers): Frequency modulated (FM) sources that sweep through a range of frequencies one at a time have the same spectral content of a broadband sound where all the frequencies are occurring at the same time. However, for the purposes of the optional Web Calculator tool, an action proponent will need to evaluate multiple frequencies to determine the most appropriate isopleth by marine mammal hearing group. NMFS recommends evaluating isopleths produced using the lowest and highest frequencies produced and evaluating which produces the largest isopleth for each hearing group, as well as considering if the source produces sound in or around a hearing groups most susceptible frequency (See Section 3.2.2).

6.2.3.1 Single Frequency (Weighting Factor Adjustment)

There are a couple of options for action proponents for determining the appropriate WFA for their broadband sound source: 1) NMFS default WFA or 2) Source-specific WFA. If neither a default nor source-specific WFA can be provided, it is recommended that the source be considered unweighted. Action proponents may rely upon a NMFS suggested default for their broadband source, which acknowledges are likely conservative (Table 8).

Table 8: NMFS suggested default weighting factor adjustments (WFAs) for broadband sources.

Source	WFA	Example Supporting Sources
Seismic airguns	1 kHz	Breitzke et al. 2008; Tashmukhambetov et al. 2008; Tolstoy et al. 2009;
Impact pile driving hammer	2 kHz	Blackwell 2005; Reinhall and Dahl 2011
Vibratory pile driving hammers	2.5 kHz	Blackwell 2005; Dahl et al. 2015a
Drilling equipment	2 kHz	Greene 1987; Blackwell et al. 2004a; Blackwell and Greene 2006

Action proponents may also rely upon a WFA based off the 95% frequency contour from measurements of their particular source. However, if the action proponent has data on the spectrum associated with their source, they are encouraged to incorporate the full auditory weighting functions, rather than relying upon a simple WFA that only accounts for weighting at one frequency.

If an action proponent decides to rely upon a source-specific WFA for their broadband source, then if the WFA is above 5 kHz for LF cetaceans, above 9 kHz for otariid pinnipeds, or above 11 kHz for phocid pinnipeds, then source should be treated as unweighted (0 dB adjustment; See Section 3.2) (Table 9; See also FICTITIOUS EXAMPLES A and B in Section 3.1.1).

Table 9: Applicability of weighting factor adjustments for broadband sources.

Source-Specific WFA	Hearing Group to be Treated as Unweighted
Above 5 kHz	LF Cetaceans
Above 9 kHz	LF Cetaceans and Otariid Pinnipeds
Above 11 kHz	LF Cetaceans, Otariid Pinnipeds, and Phocid Pinnipeds

6.2.3.2 Multiple Frequencies (Spectrum)

This option allows the action proponent to override the single frequency weighting factor adjustment by directly entering the adjustment (-dB) by hearing group. Using this option requires the action proponent to input the weighting function amplitude for each marine mammal hearing group. This option is used when the applicant has the spectrum of their sound source available or wants to make particular marine mammal hearing groups unweighted (i.e., action proponent would enter 0 dB).

By including a source's entire spectrum, this will allow an action proponent to incorporate the Technical Guidance's marine mammal auditory weighting functions over the entire broadband frequency range of the source, rather than just for one frequency via the WFA. As a result of directly relying upon a sound sources' spectrum, it will result in more realistic (i.e., likely smaller) isopleths (i.e., NMFS' preference is that spectrum data be use for broadband sources, when possible, compared to the simple WFA). However, the action proponent must provide clear evidence to NMFS of how the spectrum data were derived and used.

With the source spectrum, the action proponent can compare the unweighted source level to the weighted source level by hearing group. The weighting adjustment (-dB) is the difference between the weighted and unweighted source level (e.g., if LF cetacean weighted source level was 227.3 dB and the unweighted source level was 240 dB, then the weighting adjustment would be -12.7 dB). This adjustment can directly inputted into the optional Web Calculator tool via Step 5.

> **NOTE**: Adjustments (-dB) used in this option are either zero or a negative value (i.e., they are never positive).

6.2.4 Step 4

This Step is where the action proponent provides various details about their sound source, including source level, factors related to duration of sound exposure within a 24-h period, and propagation loss (where applicable) (Figure 26).

> **NOTE:** In this Step missing or incorrect values will be highlighted orange. Once an acceptable value has been entered, the box will no longer be highlighted.

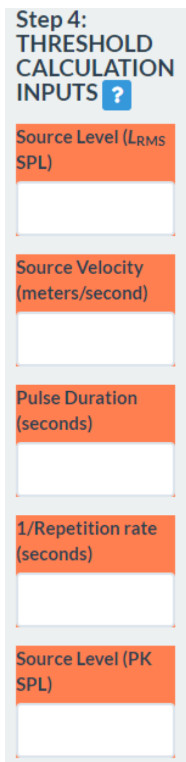


Figure 26: Screenshot illustrating threshold calculation inputs. Note: This is one example of how this window can appear (i.e., content may vary depending on sound source/source category chosen).

6.2.4.1 <u>Source Level</u>

The source level metric displayed here will depend on what type of source level is chosen in Step 2 by the action proponent. In this Step the action proponent is choosing the source level related to calculating the cumulative sound exposure level.

NOTE: For sources, such as vibratory pile driving hammers and impact pile driving hammers, true source levels (i.e., levels reference to 1 m from the source) are typically not provided. Instead for these sources, sound levels (L_{rms}, Single Strike SEL, or PK) are typically referenced 10 m from the source. Thus, for these sources, the action proponent is also asked to specify the distance of the sound level measurement.

For impulsive sources, a source level in the peak sound pressure level (PK) metric, defined as the greatest absolute instantaneous sound pressure within a specified time interval and frequency band (ANSI 1986; ANSI 2013), is also required, since impulsive sources have dual thresholds. The 2018 Revised Technical Guidance recommends that the PK thresholds are unweighted/flat-weighted within the generalized hearing range of marine mammals (i.e., 7 Hz to 160 kHz).

For airgun arrays, Galindo-Romero et al. (2015) provide methodology to predict PK SPL from SELss. Lippert et al. (2015) provides similar methodology for offshore impact pile driving activities, if values are unknown.

For seismic arrays, RMS levels are typically 10 dB lower than PK (Harris et al. 2001; Breitzke et al. 2008).

6.2.4.2 Miscellaneous Factors Related to Exposure Duration

Depending on the sound source or sound source category chosen there are various other pieces of information that are asked to account for the duration of sound exposure (listed in alphabetical order):

Activity Duration (hours) within a 24-h period

Suggested for:

- Sound Source: Stationary sonar or sonar-like source; Stationary seismic airguns (e.g. Vertical seismic profiling)

- Source Category: Non-Impulsive-Stationary-Intermittent; Impulsive-Stationary

This represents the amount of time (hours) an activity is expected to occur within a 24-h period.

NOTE: This is NOT asking for the total time (in hours) over which the source is producing sound (see Fictitious Example below).

This input is different from those for continuous sources or drilling vessels/platforms which asks the action proponent to input the *actual* amount of time the source is producing sound (i.e., Duration of Sound Production).

FICTITIOUS EXAMPLE: If an action proponent had an activity that occurred during daylight (i.e. 12 h), regardless of the pulse duration and 1/repetition rate, then the input for activity duration would be 12 h.

NOTE: The optional Web Calculator tool is flexible and allows the action proponent to specify the duration of sound production within a 24-h period. Thus, if there is enough information to determine that within the duration of sound production in a 24-h period that a receiver (animal) will only be exposed for a portion of that 24-h period, then the actual exposure duration may be used instead. If exposure duration is substituted for sound production duration, then NMFS recommends the action proponent provide information and assumptions used to support this substitution. If the substituted exposure duration varies by species and/or hearing group, it is important to remember to keep track and note which isopleths are appropriate for which hearing groups/species, since the optional Web Calculator tool will calculate isopleths based on the entered duration for all groups. Thus, the optional Web Calculator tool may need to be run multiple times to account for this variability among species/hearing groups.

Those calculations relying upon the “safe distance” methodology (e.g., mobile sources) does not ask the action proponent to specify the duration of the activity or sound production within a 24-h period. This is because this methodology is activity duration (time) independent.

Duration of Sound Production (hours) within a 24-h period
Suggested for:

- Sound Source: Stationary drilling vessels or platforms
- Source Category: Non-Impulsive-Stationary-Continuous

This is representative (typical) amount of time (hours) a sound source is producing sound within a 24-h period and is different from the *activity duration* within a 24-h period.

FICITIOUS EXAMPLE: If an action proponent was drilling two holes and each hole took ~5 hours to drill (i.e., sound produced entire 5 hours), then the activity duration would be 10 h.

NOTE: The optional Web Calculator tool is flexible and allows the action proponent to specify the duration of sound production within a 24-h period. Thus, if there is enough information to determine that within the duration of sound production in a 24-h period that a receiver (animal) will only be exposed for a portion of that 24-h period, then the actual exposure duration may be used instead. If exposure duration is substituted for sound production duration, then NMFS recommends the action proponent provide information and assumptions used to support this substitution. If the substituted exposure duration varies by species and/or hearing group, it is important to remember to keep track and note which isopleths are appropriate for which hearing groups/species, since the optional Web Calculator tool will calculate isopleths based on the entered duration for all groups. Thus, the optional Web Calculator tool may need to be run multiple times to account for this variability among species/hearing groups.

Those calculations relying upon the “safe distance” methodology (e.g., mobile sources) do not ask the action proponent to specify the duration of the activity or sound production within a 24-h period. This is because this methodology is activity duration (time) independent.

Duration to drive a single pile (minutes)
Suggested for:

- Sound Source: Vibratory pile driving hammers

The representative (typical) amount of time needed to drive a single pile in minutes associated with vibratory pile driving. This duration assume sound is produced during the entire time.

Number of pulses/shots in 1-h period
Suggested for:

- Sound Source: Stationary sonar or sonar-like source; Stationary seismic airguns (e.g., Vertical seismic profiling)
- Source Category: Non-Impulsive-Stationary-Intermittent; Impulsive-Stationary

This representative number of pulses/shots occurring within an hour. For example if one knows 1/repetition rate for their source (even though this is not directly asked using this method), they can use this to figure out the number of pulses in an hour by taking 3600 (number of seconds in an hour) divided by 1/repetition rate.

FICTITIOUS EXAMPLE: If a source has a 1/repetition rate of 15 seconds, then the number of pulses in an hour would be 240 (3600 seconds/15 seconds).

Number of piles within a 24-h period
Suggested for:
- Sound Source: Vibratory pile driving hammers; Impact pile driving hammers

The total number of piles expected to be driven within a 24-h period.

Number of strikes per pile
Suggested for:
- Sound Source: Impact pile driving hammers

This represents (typical) number of strikes per pile.

Ping/Strike/Pulse/Shot Duration (seconds)
Suggested for:
- Sound Source: Impact pile driving hammers; Stationary sonar or sonar-like source; Stationary seismic airguns (e.g., Vertical seismic profiling); Mobile sonar or sonar-like source; Mobile seismic airguns

- Source Category: Non-Impulsive-Stationary-Intermittent; Non-Impulsive-Mobile-Intermittent; Impulsive-Stationary; Impulsive-Mobile

Duration of ping/strike/pulse/shot (i.e., Window that makes up 90% of total cumulative energy (5%-95%) based on Madsen 2005). NMFS provides recommendations for strike duration (impact pile driving hammers) and shot duration for seismic airguns, if unknown by the action proponent, in Appendices B and C of this document.

1/Repetition Rate (seconds)
Suggested for:
- Sound Source: Stationary sonar or sonar-like source; Mobile sonar or sonar-like source; Stationary seismic airguns (e.g., Vertical seismic profiling); Mobile seismic airguns

- Source Category: Non-Impulsive-Stationary-Intermittent; Non-Impulsive-Mobile-Continuous; Non-Impulsive-Mobile-Intermittent; Impulsive-Stationary; Impulsive-Mobile

Number of pulses of a repeating signal in a specific time unit, normally measured in pulses per second or the time between onsets of successive pulses.

> **FICTITIOUS EXAMPLE**: If a device produces a 9-second ping every 6 seconds, then 1/repetition rate would be 15 seconds (i.e., onset between successive pulses is 15 seconds).
>
> Sometimes sonar sources may indicate pings in terms of Hz (i.e., pings per second). For example, if a sonar has a 4 Hz ping rate, this translates to a ping every 0.25 seconds (1 second/4 pings per second). Thus, 1/repetition rate would be 0.25 seconds.

Source Velocity (seconds)
Suggested for:
- Sound Source: Mobile sonar or sonar-like source; Mobile seismic airguns

- Source Category: Non-Impulsive-Mobile-Continuous; Non-Impulsive-Mobile-Intermittent; Impulsive-Mobile

This represents the source velocity (i.e., if source attached to vessel, it is the vessel speed).

6.2.4.3 Propagation Loss (x Log R)

Action proponents are only given the opportunity to specify propagation/transmission loss[10] for stationary sources (i.e., mobile sources rely upon the "safe distance" methodology, which uses spherical spreading (20 Log R) as a default that cannot be changed).

If an action proponent has site-specific propagation/transmission loss information for their stationary source, they may enter it here and specify this in the Project/Source Information of Step 1. If not, NMFS recommends that an action proponent contact us to determine an appropriate surrogate value.

> **USER TIP**: NMFS typically recommends practical spreading (15 Log R) for projects occurring in shallow, coastal areas.

6.2.4.4 Distance of source level measurement (meters)

The typical source levels reference is 1 meter from the source. However, for activities such as impact pile driving, and vibratory pile driving, the typical distance is 10 meters or more. The action proponent enters whatever value is appropriate for their specific source.

6.2.5 Step 5

This Step is where the action proponent provides information related to the incorporation of the marine mammal auditory weighting function.

The action proponent either provides a single frequency (kHz) for determining the weighting factor adjustment (Figure 27) or directly inputs the weighting function adjustments by hearing group (Figure 28), depending on what was selected in Step 3.

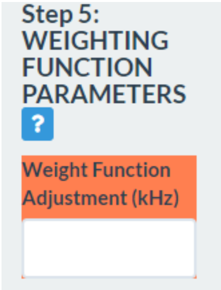


Figure 27: Screenshot illustrating incorporating weighting using a single frequency.

[10] Note: Transmission loss is conceptually different from propagation loss (i.e., propagation loss is associated with the source level, while transmission loss is associated with a measurement at a specified distance). However, in the optional Web Calculator for the sake of simplicity, the distinction between propagation and transmission loss is not made.

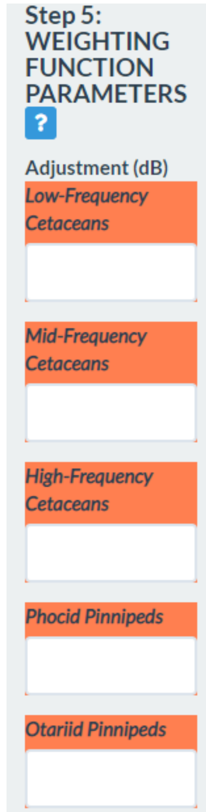


Figure 28: Screenshot illustrating incorporating weighting for each marine mammal hearing group.

NOTE: In this Step missing or incorrect values will be highlighted orange. Once an acceptable value has been entered, the box will no longer be highlighted.

Adjustments (-dB) used in this option are either zero or a negative value (i.e., they are never positive).

6.2.6 Results

These Windows summarize the weighting factor adjustments, as well as calculate the resultant isopleths.

6.2.6.1 Weighting Function Adjustment

This Window is summarizing the weighting function adjustments that are either directly provided by the action proponent or based upon the weighting factor adjustment (Figure 29).

WEIGHTING FUNCTION ADJUSTMENTS (dB)

	Low-Frequency cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
Adjustment (dB)	-0.06	-29.11	-37.55	-5.9	-4.87

Figure 29: Screenshot illustrating resultant weighting function adjustments (dB). This example is relying upon a WFA equal to 1 kHz.

6.2.6.2 Threshold Isopleth Results

This Window provides the 2018 Revised Technical Guidance thresholds and resultant isopleths associated with these thresholds, by source type (i.e., non-impulsive or impulsive) by marine mammal hearing group (Figure 30).

THRESHOLD ISOPLETHS RESULTS

Underwater Acoustic Thresholds

	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
SEL_{cum} Threshold	199	198	173	201	219
PTS Isopleth to threshold (m)	56.6	5	83.6	34.4	2.4

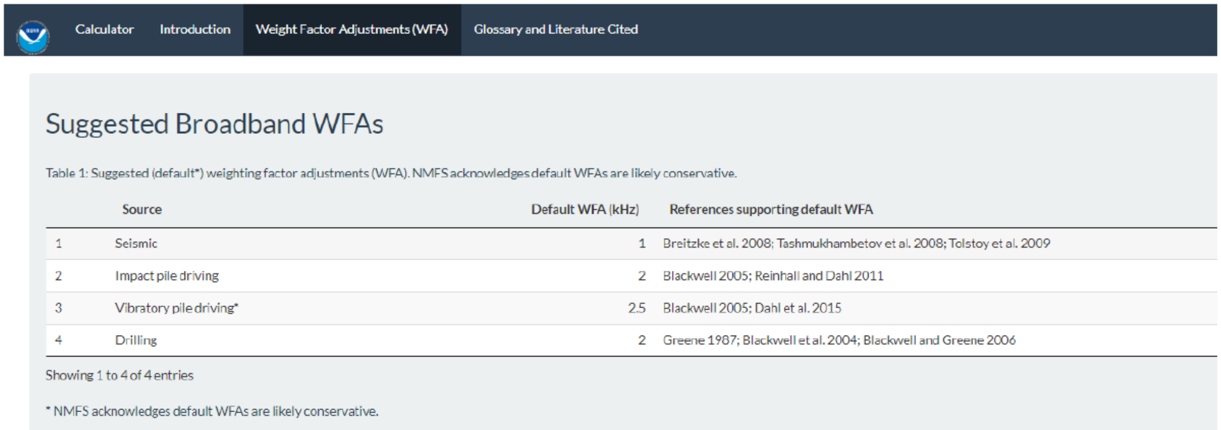
Figures 30: Screenshot illustrating resultant isopleths.

NOTE: The optional Web Calculator tool provides a means to estimates distances associated with the 2018 Revised Technical Guidance's PTS onset thresholds. Mitigation and monitoring requirements associated with a Marine Mammal Protection Act (MMPA) authorization or an Endangered Species Act (ESA) consultation or permit are independent management decisions made in the context of the proposed activity and comprehensive effects analysis, and are beyond the scope of the 2018 Revised Technical Guidance and the optional Web Calculator tool. For impulsive sources, both PTS SEL_{cum} and PK Isopleth to thresholds will be calculated. Action proponents are recommended to rely upon whatever metric provides the largest isopleth by marine mammal hearing group.

If an action proponent get output "NA" instead of a numerical isopleth associated with the PTS PK isopleth, this means the PK source level is less than or equal to the threshold for the particular marine mammal hearing group

6.3 Weighting Factor Adjustment (WFA) Tab

This Tab provides NMFS recommended defaults for various broadband sources (Figure 31).



Suggested Broadband WFAs

Table 1: Suggested (default*) weighting factor adjustments (WFA). NMFS acknowledges default WFAs are likely conservative.

	Source	Default WFA (kHz)	References supporting default WFA
1	Seismic	1	Breitzke et al. 2008; Tashmukhambetov et al. 2008; Tolstoy et al. 2009
2	Impact pile driving	2	Blackwell 2005; Reinhall and Dahl 2011
3	Vibratory pile driving*	2.5	Blackwell 2005; Dahl et al. 2015
4	Drilling	2	Greene 1987; Blackwell et al. 2004; Blackwell and Greene 2006

Showing 1 to 4 of 4 entries

* NMFS acknowledges default WFAs are likely conservative.

Figure 31: Screenshot of Weighting Factor Adjustment Tab: NMFS suggested broadband weighting factor adjustments.

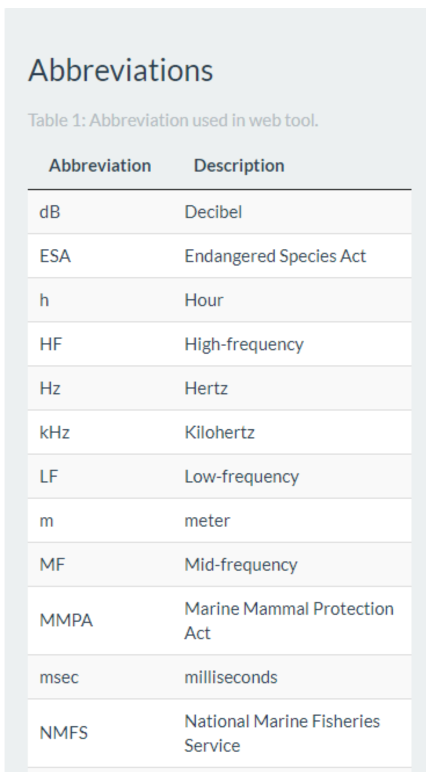
NOTE: If the action proponent has data on the spectrum associated with their source, they are encouraged to incorporate the full auditory weighting functions, rather than relying upon a simple WFA that only accounts for weighting at one frequency.

6.4 GLOSSARY AND LITERATURE CITED TAB

This tab contains three windows for abbreviations, glossary, and literature cited.

6.4.1 Abbreviations

This window provides abbreviations, acronyms, and symbols used within the optional Web Calculator tool (Figure 32).



Abbreviations

Table 1: Abbreviation used in web tool.

Abbreviation	Description
dB	Decibel
ESA	Endangered Species Act
h	Hour
HF	High-frequency
Hz	Hertz
kHz	Kilohertz
LF	Low-frequency
m	meter
MF	Mid-frequency
MMPA	Marine Mammal Protection Act
msec	milliseconds
NMFS	National Marine Fisheries Service

Figure 32: Screenshot of Abbreviations window.

6.4.2 Glossary

This window provides a glossary of terms used within the optional Web Calculator tool (Figure 33). The majority of these glossary terms can also be found in the 2018 Revised Technical Guidance (Appendix E).

Glossary

Phrase	Definition
95% Frequency contour percentile	Upper frequency below which 95% of total cumulative energy is contained (Charif et al. 2010).
Accumulation period	The amount of time a sound accumulates for the SEL_{cum} metric.
Acoustic center	Point from which outgoing wavefronts appear to diverge in the acoustic far field under free-field conditions (ISO 2017).

Figure 33: Screenshot of Glossary window.

6.4.3 Literature Cited

This window provides a list of literature cited used within the optional Web Calculator tool (Figure 34).

Literature Cited

Ahroon, W.A., R.P. Hamernik, and S.-F., Lei. 1996. The effects of reverberant blast waves on the auditory system. Journal of the Acoustical Society of America 100:2247-2257.

ANSI (American National Standards Institute). 1986. Methods of Measurement for Impulse Noise (ANSI S12.7-1986). New York: Acoustical Society of America.

ANSI (American National Standards Institute). 1995. Bioacoustical Terminology (ANSI S3.20-1995).New York: Acoustical Society of America.

ANSI (American National Standards Institute). 2005. Measurement of Sound Pressure Levels in Air (ANSI S1.13-2005). New York: Acoustical Society of America.

ANSI (American National Standards Institute). 2013. Acoustic Terminology (ANSI S1.1- 2013). New York: Acoustical Society of America.

Blackwell, S.B. 2005. Underwater Measurements of Pile Driving Sounds during the Port MacKenzie Dock Modifications, 13-16 August 2004. Juneau, Alaska: Federal Highway Administration.

Figure 34: Screenshot of Literature Cited window.

APPENDIX A: SUMMARY OF 2018 REVISED TECHNICAL GUIDANCE THRESHOLDS AND AUDITORY WEIGHTING FUNCTIONS

Table A1: Marine mammal hearing groups.

Hearing Group	Generalized Hearing Range*
Low-frequency (LF) cetaceans (baleen whales)	7 Hz to 35 kHz
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* & *L. australis*)	275 Hz to 160 kHz
Phocid pinnipeds (PW) (underwater) (true seals)	50 Hz to 86 kHz
Otariid pinnipeds (OW) (underwater) (sea lions and fur seals)	60 Hz to 39 kHz

***** Represents the generalized hearing range for the entire group as a composite (i.e., all species within the group), where individual species' hearing ranges are typically not as broad. Generalized hearing range chosen based on ~65 dB threshold from normalized composite audiogram, with the exception for lower limits for LF cetaceans (Southall et al. 2007) and PW pinniped (approximation).

Table A2: Summary of auditory weighting and exposure function parameters.*

Hearing Group	*a*	*b*	f_1 (kHz)	f_2 (kHz)	*C* (dB)	*K* (dB)
Low-frequency (LF) cetaceans	1.0	2	0.2	19	0.13	179
Mid-frequency (MF) cetaceans	1.6	2	8.8	110	1.20	177
High-frequency (HF) cetaceans	1.8	2	12	140	1.36	152
Phocid pinnipeds (PW) (underwater)	1.0	2	1.9	30	0.75	180
Otariid pinnipeds (OW) (underwater)	2.0	2	0.94	25	0.64	198

* Equations associated with 2018 Revised Technical Guidance's auditory weighting ($W_{aud}(f)$) (dB) and exposure functions ($E_{aud}(f)$) (dB):

$$W_{aud}(f) = C + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\}$$

$$E_{aud}(f) = K - 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{\left[1+(f/f_1)^2\right]^a\left[1+(f/f_2)^2\right]^b}\right\}$$

Table A3: Summary of PTS onset acoustic thresholds.

	PTS Onset Thresholds* (Received Level)	
Hearing Group	**Impulsive**	**Non-impulsive**
Low-Frequency (LF) Cetaceans	*Cell 1* $L_{p,\text{0-pk,flat}}$: 219 dB $L_{E,p,\text{ LF,24h}}$: 183 dB	*Cell 2* $L_{E,p,\text{ LF,24h}}$: 199 dB
Mid-Frequency (MF) Cetaceans	*Cell 3* $L_{p,\text{0-pk,flat}}$: 230 dB $L_{E,p,\text{ MF,24h}}$: 185 dB	*Cell 4* $L_{E,p,\text{ MF,24h}}$: 198 dB
High-Frequency (HF) Cetaceans	*Cell 5* $L_{p,\text{0-pk,flat}}$: 202 dB $L_{E,p,\text{HF,24h}}$: 155 dB	*Cell 6* $L_{E,p,\text{ HF,24h}}$: 173 dB
Phocid Pinnipeds (PW) (Underwater)	*Cell 7* $L_{p,\text{0-pk.flat}}$: 218 dB $L_{E,p,\text{PW,24h}}$: 185 dB	*Cell 8* $L_{E,p,\text{PW,24h}}$: 201 dB
Otariid Pinnipeds (OW) (Underwater)	*Cell 9* $L_{p,\text{0-pk,flat}}$: 232 dB $L_{E,p,\text{OW,24h}}$: 203 dB	*Cell 10* $L_{E,p,\text{OW,24h}}$: 219 dB

* Dual metric thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating PTS onset. If a non-impulsive sound has the potential of exceeding the peak sound pressure level thresholds associated with impulsive sounds, these thresholds are recommended for consideration.

Note: Peak sound pressure level ($L_{p,\text{0-pk}}$) has a reference value of 1 µPa, and weighted cumulative sound exposure level ($L_{E,p}$) has a reference value of 1µPa^{2}s. In this Table, thresholds are abbreviated to be more reflective of International Organization for Standardization standards (ISO 2017). The subscript "flat" is being included to indicate peak sound pressure are flat weighted or unweighted within the generalized hearing range of marine mammals (i.e., 7 Hz to 160 kHz). The subscript associated with cumulative sound exposure level thresholds indicates the designated marine mammal auditory weighting function (LF, MF, and HF cetaceans, and PW and OW pinnipeds) and that the recommended accumulation period is 24 hours. The weighted cumulative sound exposure level thresholds could be exceeded in a multitude of ways (i.e., varying exposure levels and durations, duty cycle). When possible, it is valuable for action proponents to indicate the conditions under which these thresholds will be exceeded.

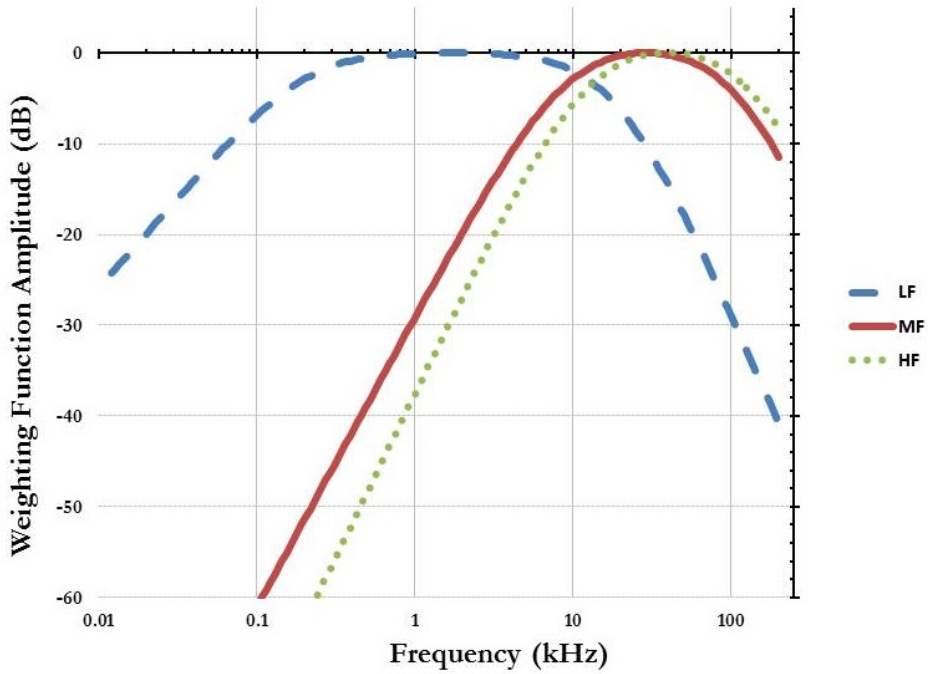


Figure A1: **Auditory weighting functions for low-frequency (LF), mid-frequency (MF), and high-frequency (HF) cetaceans.**

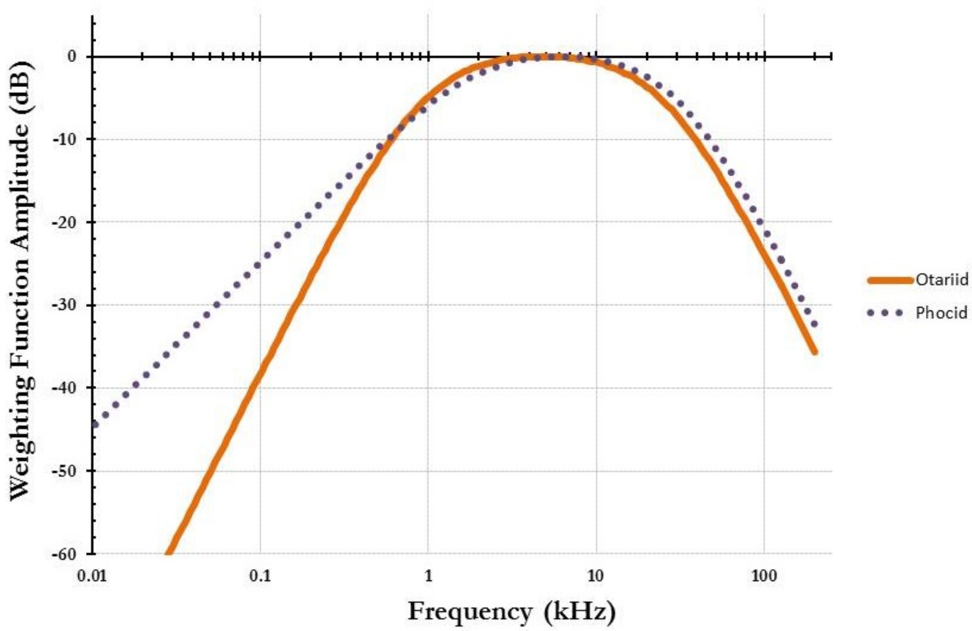


Figure A2: **Underwater auditory weighting functions for otariid (OW) and phocid (PW) pinnipeds.**

APPENDIX B: RECOMMENDED 100 MSEC (DEFAULT) PULSE DURATION FOR IMPACT PILE DRIVING ACTIVITIES

1.0 INTRODUCTION

The optional Web Calculator tool provides an optional tool for approximating isopleths associated with the Guidance's updated PTS onset thresholds. When information is unavailable, then default values are needed for substitution. NMFS has worked to provide appropriate default values for several of these cells within the optional Web Calculator tool (e.g., default weighting factor adjustments (WFAs) for various sound sources. However, it has become necessary to provide further appropriate default values, including pulse duration for impulsive sources (i.e., impact pile driving hammer strikes and seismic airgun shots (Appendix C)).

Defaults are meant to be conservative in order to encompass the broad potential range of values associated with an activity or sound source (e.g., for pile driving variation could result from water depth associated with activity, sediment characteristics, pile diameter, pile material, etc.). Thus, an action proponent is always encouraged to use activity-specific information, if available, as a substitute for using NMFS' recommended default values, as this activity-specific information will provide a more realistic representation of the isopleths associated with that activity.

> **NOTE**: When a single strike SEL source level is available, action proponents are encouraged to use this value. By doing so, there is no need to specify a pulse duration (default or otherwise).

2.0 DERIVATION OF DEFAULT PULSE DURATION FOR IMPACT PILE DRIVING ACTIVITIES

As impulsive sounds propagate through the environment, their physical characteristics begin to change. For example, pulse duration increases as a result of multipath propagation loss[11] and reverberation (e.g., Richardson 2000; Blackwell et al. 2004b; Madsen et al. 2006). Range (R) from the source, as well as water depth (H), are important factors contributing to pulse duration (i.e., more multipath arrivals in shallower water and with higher R/H ratio; Harrison and Nielsen 2007; Harrison 2011; Ainslie et al. 2014). For example, Tolstoy et al. (2009) demonstrated this with seismic airgun shots stating, "reverberations in the shallow arrivals mean that the 90% RMS integration window is longer, whereas deep arrivals are more impulsive and therefore have a shorter integration window." This same phenomenon also occurs for impact pile driving hammer strikes (e.g., Robinson et al. 2007). Thus, NMFS evaluated the available data to determine what would be an appropriate default pulse duration for impact pile driving activities considering these various factors.

2.1 ANALYSIS OF CALTRANS (2015) COMPENDIUM

The Compendium (Appendix I) within Caltrans (2015) provides one of the most comprehensive resources for previously measured coastal pile driving activities. Using the summary data provided at the beginning of this compendium, 10 m levels expressed as single strike SEL, PK, and L_{rms} sound levels were analyzed for all pile types (e.g., steel, concrete) (Table B1).

[11] Multipath propagation loss occurs whenever there is more than one propagation path between the source and receiver (i.e., direct path and paths from reflections off the surface and bottom or reflections within a surface or deep-ocean duct; Urick 1983).

Table B1: Caltrans (2015) Compendium analysis.*

PEAK-RMS			PEAK-SEL			RMS-SEL	
Mean	**17.9393939**		**Mean**	**28.48438**		**Mean**	**11.24**
Standard En	0.82328547		Standard Error	0.597196		Standard Error	0.354055
Median	15.5		Median	28		Median	10.5
Mode	**15**		**Mode**	**25**		**Mode**	**10**
Standard De	6.68840279		Standard Deviatio	4.777567		Standard Deviat	2.503549
Sample Vari	44.7347319		Sample Variance	22.82515		Sample Variance	6.267755
Kurtosis	4.64041808		Kurtosis	0.147072		Kurtosis	1.006221
Skewness	1.88360263		Skewness	0.407213		Skewness	-0.21923
Range	33		Range	24		Range	12
Minimum	10		Minimum	19		Minimum	4
Maximum	43		Maximum	43		Maximum	16
Sum	1184		Sum	1823		Sum	562
Count	66		Count	64		Count	50
Confidence	1.64421463		Confidence Level(	1.193401		Confidence Leve	0.711501

* Difference (dB) between 10 m levels provided in various metrics. These data used to were determine appropriate surrogate pulse duration (i.e., difference between L_{rms} and single strike SEL).

From this analysis, the mean difference between L_{rms} and single strike SEL mean is 11.24 dB, while the mode is 10 dB. A 10-dB difference translates to a pulse duration of 100 msec via Equation B1:

$$SEL_{ss} = L_{rms\ ss} + 10 \text{ Log (duration in seconds)} \qquad \textbf{Equation B1}$$

Solve equation assuming a 10 dB difference (mode from Table B1) between SEL_{ss} and $L_{rms\ ss}$:
-10 dB = 10 Log (duration)
-1 = Log (duration)
 = 0.1 seconds (100 msec)

An 11.24-dB difference (mean from Table B1) translates to a pulse duration of ~75 msec via Equation B1.

Thus, the data in the Compendium support the general statement from its Appendix IV, Section 4 Underwater Noise Monitoring Plan that states, “that 90 percent of the acoustic energy for most pile driving impulses occurred over a 50 to 100 millisecond period with most of the energy concentrated in the first 30 to 50 milliseconds.”

2.2 OTHER AVAILABLE MEASUREMENTS

In addition to the Caltrans (2015) Compendium, there are various other reports and publications available that provide information on pulse duration associated with impact pile driving activities. For example, other reported measurements of impact pile driving, associated with both windfarm and other construction activities, pulse durations of 50 and 100 msec have been reported at distances of 1 km or closer to the source (e.g., Blackwell et al. 2005; Bailey et al. 2010; de Jong and Ainslie 2012; Illingsworth & Rodkin 2014).

Finally, Dr. Peter Dahl (2016) recommended “50 ms[ec] (0.05 sec) as notional pulse length for range 100 m; assume it is less than this for closer ranges (approaching 10 ms) and more than this for longer ranges (approaching 100 ms)” based on analysis of pile driving activities in Puget Sound (Dahl et al. 2015b).

2.3 WCR Pile Driving Calculator[12] for Fish Injury Thresholds

The NMFS West Coast Region (WCR) Pile Driving Calculator for fishes recommends estimating single strike SEL source levels, when no direct measurement is available based on reducing the peak sound pressure source level by 25 dB for coastal pile driving activities.[13] Additionally, this same calculator recommends estimating L_{rms} source levels sound pressure when no direct measurement is available based on reducing the peak sound pressure source level by 15 dB. Note that these recommended values are supported by data from Caltrans (2015) (See Table B1 in this document).

Thus, based on these recommendations, this results in a 10-dB difference between single strike SEL and L_{rms} values (i.e., single strike SEL is 10 dB lower than L_{rms}), which translates to a pulse duration of 100 msec via Equation B1.

3.0 RECOMMENDED DEFAULT PULSE DURATION FOR IMPACT PILE DRIVING ACTIVITIES

Based on the information summarized above, NMFS is recommending a default value of 100 msec be used in the optional Web Calculator tool for impact pile driving activities when a single strike SEL source level is unavailable. Again, if an action proponent as activity-specific information suggesting an alternative value than the suggested default, it is recommended that the most appropriate value be used.

[12] Posted on Caltrans web site.

[13] The relationship between peak sound pressure level and single strike SEL may be different for pile driving associated with offshore windfarms (Lippert et al. 2015).

APPENDIX C: RECOMMENDED 100 MSEC (DEFAULT) PULSE DURATION FOR SEISMIC ACTIVITIES (AIRGUNS)

1.0 INTRODUCTION

The optional Web Calculator tool provides a means for approximating isopleths associated with the Technical Guidance's updated PTS onset thresholds. However, there is a need for default values, when information is unavailable. NMFS has worked to provide appropriate default values for several of these cells within the optional Web Calculator tool (e.g., default weighting factor adjustments (WFAs) for various sound sources). However, it has become necessary to provide further appropriate default values, including pulse duration for impulsive sources (i.e., impact pile driving hammer strikes (Appendix B) and seismic airgun shots).

Defaults are conservative in order to encompass the broad potential range of values associated with an activity or sound source (e.g., for seismic airgun shots variation could result from water depth or other environmental parameters associated with activity). Thus, an action proponent is always encouraged to use activity-specific information, if available, as a substitute for using NMFS' recommended default values, as this activity-specific information will provide a more realistic representation of the isopleths associated with that activity.

> **NOTE**: When a single shot SEL source level is available, action proponents are encouraged to use this value. By doing so, there is no need to specify a pulse duration (e.g., default or otherwise).

2.0 DERIVATION OF DEFAULT PULSE DURATION FOR SEISMIC ACTIVITIES (AIRGUNS)

As impulsive sounds propagate through the environment, their physical characteristics begin to change. For example, pulse duration increases with multipath propagation loss[14] and reverberation (e.g., Richardson 2000; Blackwell et al. 2004b; Madsen et al. 2006). Range (R) from the source, as well as water depth (H), are important factors contributing to pulse duration (i.e., more multipath arrivals in shallower water and with higher R/H ratio; Harrison and Nielsen 2007; Harrison 2011; Ainslie et al. 2014). For example, Tolstoy et al. (2009) demonstrated this with seismic airgun shots stating, "reverberations in the shallow arrivals mean that the 90% RMS integration window is longer, whereas deep arrivals are more impulsive and therefore have a shorter integration window." Additionally, frequency content also factors into pulse duration, with those shots with more high-frequency content being shorter (HESS 1999). Moreover, airgun arrays with larger volumes typically have more low-frequency energy compared to those with smaller volumes (Watson et al. 2016). Thus, NMFS evaluated the available data to determine what would be an appropriate default pulse duration for seismic activities involving airguns considering these various factors.

2.1 AVAILABLE MEASUREMENTS

Table C1 provides a summary of available airgun shots measurements provided in the metrics of single shot sound exposure level (SEL) and root mean square (L_{rms}) sound pressure level such that pulse duration can be derived.

[14] Multipath propagation loss occurs whenever there is more than one propagation path between the source and receiver (i.e., direct path and paths from reflections off the surface and bottom or reflections within a surface or deep-ocean duct; Urick 1983).

Table C1: Summary of Available Measurements

Study	Water Depth	Measurement Distances	Array Size	Difference between L_{rms} - SEL[†]	Pulse Duration
Richardson 1997; Harris et al. 2001	3-17 m	up to 2 km	1,320 in^3	~10 dB	100 msec
Richardson 1999	2-5 m	up to 3 km		~10 dB	100 msec
McCauley et al. 2000	30-120 m	up to 22.1 km	2,678 in^3	11.4 to 14.6 dB*	35 to 72 msec
Patterson et al. 2007	40 m	up to 0.3 km	3,147 in^3	~10 dB[+]	~100 msec
Tolstoy et al. 2009	~50 m	up to 15 km	6,600 in^3	~8 dB	158 msec
Tolstoy et al. 2009	~1600 m	up to 4 km	6,600 in^3	~14 dB	40 msec
Diebold et al. 2010	~50 m	up to 15 km	3,300 in^3	~8-10 dB	10 to 158 msec
Diebold et al. 2010	~1600 m	up to 2 km	3,300 in^3	10-20 dB^	10 to 100 msec

* This study reports equivalent energy (proportional to energy). Differences displayed are mean values.
[+] 8.5 dB (141 ms) difference with increasing range (out to 3 km)
^5-10 dB difference with increasing range (2 to 6 km)
[†]A 10-dB difference translates to a pulse duration of 100 msec via Equation C1:

SEL = L_{rms} + 10 Log (duration in seconds) **Equation C1**
Solve equation assuming a 10 dB difference between SEL and L_{rms}:
-10 dB = 10 Log (duration)
-1 = Log (duration)
= 0.1 seconds (100 msec)

Other monitoring efforts have reported pulse durations of ~100 msec or less at distances 1 km or less from the source (e.g., Reiser et al. 2010; Hartin et al. 2011; Beland 2013), while others have reported a pulse duration of 200 msec at distances ~1 km from the source (e.g., Greene and Richardson 1988)

Often for modeling purposed, 100 msec is chosen as representative pulse duration value for airgun shots expected within a few kilometers from the source (e.g., MacGillivray and Chapman 2005; NSF and USGS 2011; BOEM 2016). For their evaluation of marine mammal audibility of shallow-water (40 m) survey sources, MacGillivray et al. (2014) assumed an airgun array to have pulse duration of 100 msec.

BOEM (2014) estimated range-dependent SPL-SEL offsets (Figure C1) by combining full waveform estimations using idealized flat bottom models with water depths ranging from 40 to 1000 with data obtained during field measurements with bottom types of sand (40 and 150 m models) and clay (1000 m model).

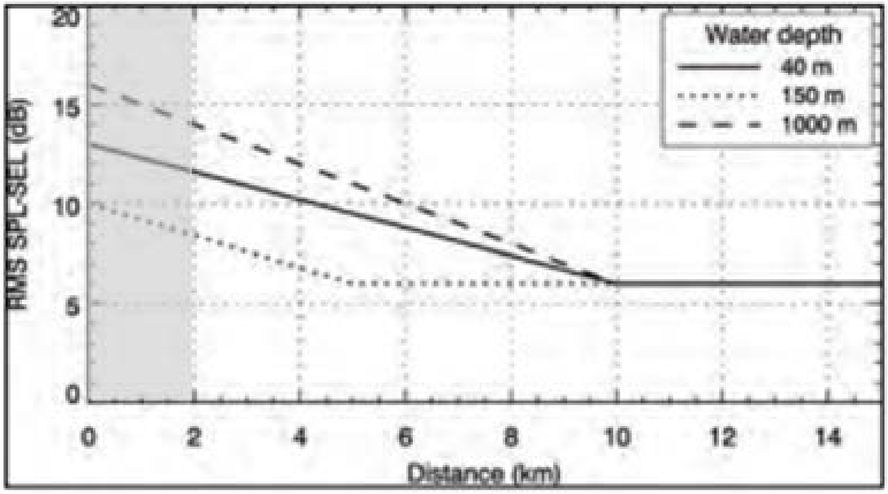


Figure C1: SPL-SEL conversion functions for different water depths (BOEM 2014). The gray shading indicates closer distances where the likelihood of PTS is higher.

Figure C1 shows that the SPL-SEL offset tends to be larger at closer distances (km), where the pulse duration is short, and diminishes at longer distances, where the pulse duration increases as a result of reverberation/multipath propagation loss. Within 2 km of the source, the SPL-SEL offset is $\geq$ 8 dB, which results in a pulse duration of 158 msec or shorter for the majority of depths. Thus, choosing a 100 msec default pulse duration is conservative in most situations, unless there is site-specific information (i.e., shallow water, etc.) indicating that there is a more appropriate pulse duration (i.e., a default pulse duration longer than 100 msec is more appropriate).

3.0 RECOMMENDED DEFAULT PULSE DURATION FOR SEISMIC ACTIVITIES (AIRGUNS)

Based on the information summarized above, NMFS is recommending a default value of 100 msec for use in the optional Web Calculator tool for seismic activities involving airguns when a single shot SEL source level is unavailable. Again, an action proponent can use activity-specific information, if available, instead of relying on the default value.

APPENDIX D: GLOSSARY

95% Frequency contour percentile: Upper frequency below which 95% of total cumulative energy is contained (Charif et al. 2010).

Accumulation period: The amount of time a sound accumulates for the SEL_{cum} metric.

Acoustic center: Point from which outgoing wavefronts appear to diverge in the acoustic far field under free-field conditions (ISO 2017).

Acoustic far field: Spatial region in a uniform medium where the direct-path field amplitude, compensated by absorption loss, varies inversely with range (ISO 2017).

Auditory weighting function: Auditory weighting functions take into account what is known about marine mammal hearing sensitivity and susceptibility to noise-induced hearing loss and can be applied to a sound-level measurement to account for frequency-dependent hearing (i.e.,. an expression of relative loudness as perceived by the ear)(Southall et al. 2007; Finneran 2016). Specifically, this function represents a specified frequency-dependent characteristic of hearing sensitivity in a particular animal, by which an acoustic quantity is adjusted to reflect the importance of that frequency dependence to that animal (ISO 2017). Similar to OSHA (2013), marine mammal auditory weighting functions in this document are used to reflect the risk of noise exposure on hearing and not necessarily capture the most sensitive hearing range of every member of the hearing group.

Bandwidth: Bandwidth (Hz or kHz) is the range of frequencies over which a sound occurs or upper and lower limits of frequency band (ANSI 2005). Broadband refers to a source that produces sound over a broad range of frequencies (for example, seismic airguns), while narrowband or tonal sources produce sounds over a more narrow frequency range, typically with a spectrum having a localized a peak in amplitude (for example, sonar) (ANSI 1986; ANSI 2005).

Broadband: See “bandwidth.”

Continuous sound: A sound whose sound pressure level remains above ambient sound during the observation period (ANSI 2005).

Decibel (dB): One-tenth of a bel. Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power (ANSI 2013).

Frequency: The number of periods occurring over a unit of time (unless otherwise stated, cycles per second or hertz) (Yost 2007).

Hertz (Hz): Unit of frequency corresponding to the number of cycles per second. One hertz corresponds to one cycle per second.

Impulsive sound: Sound sources that produce sounds that are typically transient, brief (less than 1 second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay (ANSI 1986; NIOSH 1998; ANSI 2005). They can occur in repetition or as a single event. Examples of impulsive sound sources include explosives, seismic airguns, and impact pile driving hammers.

Intermittent sound: Interrupted levels of low or no sound (NIOSH 1998) or bursts of sounds separated by silent periods (Richardson and Malme 1993). Typically, intermittent sounds have a more regular (predictable) pattern of bursts of sounds and silent periods (i.e., duty cycle).

Isopleth: A line drawn through all points having the same numerical value. In the case of sound, the line has equal sound pressure or exposure levels.

Mean-square sound pressure: Integral over a specified time interval of squared sound pressure divided by the duration of the time interval, for a specified frequency range (ISO 2017).

Narrowband: See "bandwidth."

Non-impulsive sound: Sound sources that produce sounds that can be broadband, narrowband or tonal, brief or prolonged, continuous or intermittent) and typically do not have a high peak sound pressure with rapid rise time that impulsive sounds do. Examples of non-impulsive sound sources include marine vessels, machinery operations/construction (e.g., drilling), certain sonar (e.g. tactical, navigational, and scientific), and vibratory pile driving hammers.

Octave: The interval between two sounds having a basic frequency ratio of two (Yost 2007). For example, one octave above 400 Hz is 800 Hz. One octave below 400 Hz is 200 Hz.

Omnidirectional: Receiving or transmitting signals in all directions (i.e., variation with direction is designed to be as small as possible).

One-third octave (base 10): The frequency ratio corresponding to a decidecade or one tenth of a decade (ISO 2017).

Peak sound pressure (p_{pk}): Greatest magnitude of the sound pressure during a specified time interval, for a specified frequency range. Can arise from a positive or negative sound pressure (ISO 2017).

Peak sound pressure level (PK; re: 1 μPa): Twenty times the logarithm of the base 10 of the ratio of peak sound pressure, p_{pk}, to the specified reference value, p_0, in decibels (ISO 2017).

Permanent threshold shift (PTS): A permanent, irreversible increase in the threshold of audibility at a specified frequency or portion of an individual's hearing range above a previously established reference level. The amount of permanent threshold shift is customarily expressed in decibels (ANSI 1995; Yost 2007). Available data from humans and other terrestrial mammals indicate that a 40 dB threshold shift approximates PTS onset (see Ward et al. 1958, 1959; Ward 1960; Kryter et al. 1966; Miller 1974; Ahroon et al. 1996; Henderson et al. 2008).

Power spectral density: the distribution of acoustic power into frequency components composing that signal.

Pulse duration: For impulsive sources, window that makes up 90% of total cumulative energy (5%-95%) (Madsen 2005).

Propagation loss (PL): Difference between source level in a specified direction and root mean square sound pressure level at a specified position (ISO 2017). Note: Propagation loss is conceptually different from transmission loss (i.e., propagation loss is associated with the source level, while transmission loss is associated with a measurement at a specified distance).

Received level: The level of sound at a specified distance of interest, r, (i.e., at the animal or receiver). Note: Received level is conceptually different from source level (i.e., different quantities with different reference values).

Repetition rate: Number of pulses of a repeating signal in a specific time unit, normally measured in pulses per second.

Root-mean-square sound pressure level (L_{rms}; re: 1 μPa): Ten times the logarithm to the base 10 of the ratio of the mean-square sound pressure to the specified reference value in decibels (ISO 2017).

Single Strike/Pulse/Ping/Strike Sound Exposure Level (SEL$_{ss}$; re: 1μPa^2 s): A measure of sound level that takes into account the duration of the signal, which in this case would be the duration of a single strike, ping, pulse, or strike. Ten times the logarithm to the base 10 of the ratio of time-integrated squared sound pressure to the specified reference value in decibels

Sound Exposure Level (SEL_{cum}; re: 1µPa^2 s): A measure of sound level that takes into account the duration of the signal. Ten times the logarithm to the base 10 of the ratio of time-integrated squared sound pressure to the specified reference value in decibels (ISO 2017).

Sound Pressure Level (SPL): A measure of sound level that represents only the pressure component of sound. Ten times the logarithm to the base 10 of the ratio of time-mean square pressure of a sound in a stated frequency band to the square of the reference pressure (1 µPa in water) (ANSI 2013).

Source Factor: Product of the square of distance from the acoustic center of a source, in a specified direction, and mean-square sound pressure in the acoustic far field that distance.

Source Level (SL): Sound pressure level measured in a given radian direction, corrected for absorption, and scaled to a reference distance (Morfey 2001). Ten times the logarithm to the base 10 of the ratio of the source factor to the specified reference value in decibels (ISO 2017). Note: Source level is conceptually different from received level (i.e., different quantities with different reference values).

Spectral/spectrum: Of or relating to frequency component(s) of sound. The spectrum of a function of time is a description of its resolution into components (frequency, amplitude, etc.). The spectrum level of a signal at a particular frequency is the level of that part of the signal contained within a band of unit width and centered at a particular frequency (Yost 2007).

Time-integrated squared sound pressure: Integral of the square of sound pressure over a specified time interval or event, for a specified frequency range (ISO 2017).

Transmission Loss (TL): Reduction in a specified level between two specified points that are within an underwater acoustic field (ISO 2017). Note: Transmission loss is conceptually different from propagation loss (i.e., propagation loss is associated with the source level, while transmission loss is associated with a measurement at a specified distance).

LITERATURE CITED

Ahroon, W.A., R.P. Hamernik, and S.-F., Lei. 1996. The effects of reverberant blast waves on the auditory system. Journal of the Acoustical Society of America 100:2247-2257.

Ainslie, M.A., P.H. Dahl, C.A.F. de Jong, and R.M. Laws. 2014. Practical spreading laws: The snakes and ladders of shallow water acoustics. Proceedings 2nd International Conference and Exhibition on Underwater Acoustics, UA2014, 22-27 June, Rhodes, Greece.

ANSI (American National Standards Institute). 1986. Methods of Measurement for Impulse Noise (ANSI S12.7-1986). New York: Acoustical Society of America.

ANSI (American National Standards Institute). 1995. Bioacoustical Terminology (ANSI S3.20-1995).New York: Acoustical Society of America.

ANSI (American National Standards Institute). 2005. Measurement of Sound Pressure Levels in Air (ANSI S1.13-2005). New York: Acoustical Society of America.

ANSI (American National Standards Institute). 2009. Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters (ANSI S1.11-2009). New York: Acoustical Society of America.

ANSI (American National Standards Institute). 2013. Acoustic Terminology (ANSI S1.1- 2013). New York: Acoustical Society of America.

Bailey, H., B. Senior, D. Simmons, J. Rusin, G. Picken, and P.M. Thompson. 2010. Assessing underwater noise levels during pile-driving a tan offshore windfarm and its potential effects on marine mammals. Marine Pollution Bulletin 60:888-897.

Beland, J.A., D.S. Ireland, L.N. Bisson, and D. Hannay. (eds.) 2013. Marine mammal monitoring and mitigation during a marine seismic survey by ION Geophysical in the Arctic Ocean, October-November 2012: 90-day report. LGL Rep. P1236. Rep. from LGL Alaska Research Associates Inc., LGL Ltd., and JASCO Research Ltd. for ION Geophysical, Nat. Mar. Fish. Serv., and U.S. Fish and Wild. Serv. 156 pp, plus appendices.

Blackwell, S.B. 2005. Underwater Measurements of Pile Driving Sounds during the Port MacKenzie Dock Modifications, 13-16 August 2004. Juneau, Alaska: Federal Highway Administration.

Blackwell, S.B., C.R. Greene, Jr., and W.J. Richardson. 2004a. Drilling and operational sounds from an oil production island in the ice-covered Beaufort Sea. Journal of the Acoustical Society of America 116: 3199-3211.

Blackwell, S.B., J.W. Lawson, and M.T. Williams. 2004b. Tolerance by ringed seals (*Phoca hispida*) to impact pipe-driving and construction sounds at an oil production island. Journal of the Acoustical Society of America 115:2346–2357.

Blackwell, S.B., and C.R. Green, Jr. 2006. Sounds from an oil production island in the Beaufort Sea in summer: Characteristics and contribution of vessels. Journal of the Acoustical Society of America 119: 182-196.

BOEM (Bureau of Ocean Energy Management). 2014. Atlantic OCS Proposed Geological and Geophysical Activities Mid-Atlantic and South Atlantic Planning Areas. Final Programmatic Environmental Impact Statement. New Orleans, Louisiana: U.S. Department of Interior, Bureau of Ocean Energy Management.

BOEM (Bureau of Ocean Energy Management). 2016. Gulf of Mexico OCS Proposed Geological and Geophysical Activities Western, Central, and Eastern Planning Areas. Draft Programmatic Environmental Impact Statement. New Orleans, Louisiana: U.S. Department of Interior, Bureau of Ocean Energy Management.

BOEM (Bureau of Ocean Energy Management). 2017. Gulf of Mexico OCS Proposed Geological and Geophysical Activities. Final Environmental Impact Statement, OCS EIS/EA BOEM 2017-051. New Orleans, Louisiana: Department of the Interior.

Breitzke, M., O. Boebel, S. El Naggar, W. Jokat, and B. Werner. 2008. Broad-band calibration of marine seismic sources used by R/V Polarstern for academic research in polar regions. Geophysical Journal International 174: 505-524.

Caltrans (California Department of Transportation). 2015. Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish. November 2015. Sacramento, California: California Department of Transportation.

Charif, R.A., A.M. Waack, and L.M. Strickman. 2010. Raven Pro 1.4 User’s Manual. Ithaca, New York: Cornell Lab of Ornithology.

Dahl, P. 2016. Personal communication (email) with Benjamin Laws (NMFS-PR) on 1 August, 2016.

Dahl, P.H., P.G. Reinhall, and D.M. Farrell. 2012. Transmission Loss and Range and Depth Scales Associated with Impact Pile Driving. Proceedings 11th European Conference on Underwater Acoustics, 2-6 July 2012, Edinburgh, United Kingdom.

Dahl, P.H., D.R. Dall'Osto, and D.M. Farrell. 2015a. The underwater sound field from vibratory pile driving. Journal of the Acoustical Society of America 137: 3544–3554.

Dahl, P., C.A.F. de Jong, and A.N. Popper. 2015b. The underwater sound field from impact pile driving and its potential effects on marine life. Acoustics Today 11:18-25.

de Jong, C.A.F, and M.A. Ainslie. 2012. Underwater sound due to piling activities for Prinses Amaliawindpark. TNO Report: 2012 R10081. The Hague, The Netherlands: Netherlands Organisation for Applied Scientific Research (TNO).

Diebold, J.B., M. Tolstoy, L. Doermann, S.L. Nooner, S.C. Webb, and T.J. Crone. 2010. R/V Marcus G. Langseth seismic source: Modeling and calibration. Geochemistry Geophysics Geosystems, 11, Q12012, doi:10.1029/2010GC003216.

Finneran, J.J. 2016. Auditory weighting functions and TTS/PTS exposure functions for cetaceans and marine carnivores, Technical Report 3026. December 2016. San Diego, California: SPAWAR Systems Center Pacific.

Forest, T.G. 1994. From sender to receiver: Propagation and environmental effects on acoustic signals. American Zoologist 34:644-654.

Frankel, A.S., W.T. Ellison, and J. Buchanan. 2002. Application of the Acoustic Integration Model (AIM) to predict and minimize environmental. Oceans 2002 MTS/IEEE Conference 3: 1438-1443.

Galindo-Romero, M., T. Lippert, and A. Gavrilov. 2015. Empirical prediction of peak pressure levels in anthropogenic impulsive noise. Part I: Airgun arrays signals. Journal of the Acoustical Society of America 138: EL540.

Greene, R. 1987. Characteristics of oil industry dredge and drilling sounds in the Beaufort Sea. Journal of the Acoustical Society of America 82: 1315-1324.

Greene, R., and W.J. Richardson. 1988. Characteristics of marine seismic survey sounds in the Beaufort Sea. Journal of the Acoustical Society of America 83:2246-2254.

Harris, R.E., G.W. Miller, and W.J. Richardson. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. Marine Mammal Science 17:795-812.

Harrison, C.H. 2011.Target time smearing with short transmissions and multipath propagation. Journal of the Acoustical Society of America 130:1282-1286.

Harrison, C.H., and P.L. Nielsen. 2007. Multipath pulse shapes in shallow water: Theory and simulation. Journal of the Acoustical Society of America 121:1362-1373.

Hartin, K.G., L.N. Bisson, S.A. Case, D.S. Ireland, and D. Hannay. (eds.) 2011. Marine mammal monitoring and mitigation during site clearance and geotechnical surveys by Statoil USA E&P Inc. in the Chukchi Sea, August–October 2011: 90-day report. LGL Rep. P1193. Rep. from LGL Alaska Research Associates Inc., LGL Ltd., and JASCO Research Ltd. for Statoil USA E&P Inc., Nat. Mar. Fish. Serv., and U.S. Fish and Wild. Serv. 202 pp, plus appendices.

Henderson, D., B. Hu, and E. Bielefeld. 2008. Patterns and mechanisms of noise-induced cochlear pathology. Pages 195-217 in Schacht, J., A.N. Popper, and R.R Fay, eds. Auditory Trauma, Protection, and Repair. New York: Springer.

HESS (High Energy Seismic Survey). 1999. High energy seismic survey review process and interim operational guidelines for marine surveys offshore Southern California. Prepared for The California State Lands Commission and The United States Minerals Management Service Pacific Outer Continental Shelf Region. Camarillo, California: High Energy Seismic Survey Team.

Illingworth & Rodkin. 2014. 2013 Cook Inlet exploratory drilling program-Underwater sound source verification assessment. Petaluma, California: Illingworth & Rodkin, Inc.

ISO (International Organization for Standardization. 2017. Underwater Acoustics-Terminology, ISO 18405. Geneva, Switzerland: International Organization for Standardization.

Kryter, K.D., W.D. Ward, J.D. Miller, and D.H. Eldredge. 1966. Hazardous Exposure to Intermittent and Steady-State Noise. Journal of the Acoustical Society of America 39:451-464.

Lippert, T., M. Galindo-Romero, A.N. Gavrilov, and O. von Estorff. 2015. Empirical estimation of peak pressure level from sound exposure level. Part II: Offshore impact pile driving noise. The Journal of the Acoustical Society of America 138: EL287-EL292.

Lippert, T., M.A. Ainslie, and O. von Estorff. 2018. Pile driving acoustics made simple: Damped cylindrical spreading model. Journal of the Acoustical Society of America 143:310-317.

MacGillivray, A.O., and N.R. Chapman. 2005. Results from an acoustic modelling study of seismic airgun survey noise in Queen Charlotte Basin. Victoria, British Columbia, Canada: University of Victoria, School of Earth and Ocean Sciences.

MacGillivray, A.O., R. Racca, and Z. Li. 2014. Marine mammal audibility of selected shallow-water survey resources. Journal of the Acoustical Society of America 135:EL35-EL40.

Madsen, P.T. 2005. Marine mammals and noise: Problems with root mean square sound pressure levels for transients. Journal of the Acoustical Society of America 117: 3952– 3957.

Madsen, P.T., M. Johnson, P.J.O. Miller, N. Aguillar Soto, J. Lynch, and P. Tyack. 2006. Quantitative measure of air-gun pulses recorded on sperm whales (*Physeter macrocephalus*) using acoustic tags during controlled exposure experiments. Journal of the Acoustical Society of America 120:2366-2379.

McCauley, R. D., J. Fewtrell, A.J. Duncan, C. Jenner, M.N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdock, and K. McCabe. 2000. Marine seismic surveys-a study of environmental implications. Australian Petroleum Production and Exploration Association Journal 2000:692-708.

Miller, J.D. 1974. Effects of noise on people. Journal of the Acoustical Society of America 56:729 764.

Mountain, D.C., D. Anderson, A. Brughera, M. Cross, D.S. Houser, N. Musleh, M. Porter, and M. Siderius. 2011. The ESME Workbench: Simulating the impact of anthropogenic sound on marine mammal. Pages 217-219. In Popper, A.N., and A. Hawkins, eds. The Effects of Noise on Aquatic Life. New York: Springer.

Morfey, C.L. 2001. Dictionary of Acoustics. New York: Academic Press.

NIOSH (National Institute for Occupational Safety and Health). 1998. Criteria for a recommended standard: Occupational noise exposure. Cincinnati, Ohio: United States Department of Health and Human Services.

NMFS (National Marine Fisheries Service). 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-55, 168 p.

NMFS (National Marine Fisheries Service). 2018a. Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59, 168 p.

NMFS (National Marine Fisheries Service). 2018b. Manual for Optional User Spreadsheet Tool (Version 2.0) for: 2018 Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0). U.S. Dept. of Commerce, NOAA. 109 p.

NSF (National Science Foundation) and USGS (U.S. Geological Survey). 2011. Final Programmatic Environmental Impact Statement/Overseas Environmental Impact Statement for Marine Seismic Research Funded by the National Science Foundation or Conducted by the U.S. Geological Survey. Arlington, Virginia: National Science Foundation.

NOAA (National Oceanic and Atmospheric Administration). 2018. User Manual for Optional User Spreadsheet Tool for 2018 Revisions to Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts Federal Register 83(185):48291-48292.

OSHA (Occupational Safety & Health Administration). 2013. OSHA Technical Manual. Washington, D.C.: United States Department of Labor.

Patterson, H., S.B. Blackwell, B. Haley, A. Hunter, M. Jankowski, R. Rodrigues, D. Ireland and D.W. Funk. 2007. Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July–September 2006: 90-day report. LGL Draft Rep. P891-1. Rep. from LGL Alaska Research Associates Inc., Anchorage, AK, LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Goleta, CA, for Shell Offshore Inc., Houston, TX, and Nat. Mar. Fish. Serv., Silver Spring, MD. 199 p.

Reinhall, P.G., and P.H. Dahl. 2011. Underwater Mach wave radiation from impact pile driving: Theory and observation. Journal of the Acoustical Society of America 130: 1209–1216.

Reiser, C. M, D. W. Funk, R. Rodrigues, and D. Hannay. 2010. Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore, Inc. in the Alaskan Chukchi Sea, July–October 2009: 90-day report. LGL Rep. P1112-1. Rep. from LGL Alaska Research Associates Inc. and JASCO Research Ltd. for Shell Offshore Inc., Nat. Mar. Fish. Serv., and U.S. Fish and Wild. Serv. 104 pp, plus appendices.

Richardson, W.J. 1997. Northstar marine mammal monitoring program, 1996: Marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Report TA2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Silver Spring, MD.

Richardson, W.J. 1999. Marine mammal and acoustical monitoring of Western Geophysical's Open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Report TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and Nat. Mar. Fish. Serv., Silver Spring, MD. 390 p.

Richardson, W.J. 2000. Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1999. LGL Rep. TA2313-4. King City, Ontario, Canada: LGL Ltd.

Richardson, W.J., and C.I. Malme. 1993. Man-made noise and behavioral responses. Pages 631-700. In Burns, J.J., J.J. Montague, and C.J. Cowles, eds. The Bowhead Whale. The Society for Marine Mammalogy, Special Publication Number 2.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. New York: Academic Press.

Robinson, S.P., P.A. Lepper, and J. Ablitt. 2007. The measurement of the underwater radiated noise from marine piling including characterisation of a "soft start" period. Proceedings of IEEE "Ocean 2007"Conference, 6 p.

Schecklman S., N. Laws, L.M. Zurk, and M.A. Siderius. 2015. A computational method to predict and study underwater noise due to pile driving. Journal of the Acoustical Society of America 138**:**258–266.

Sivle, L.D., P.H. Kvadsheim, and M.A. Ainslie. 2014. Potential for population-level disturbance by active sonar in herring. ICES Journal of Marine Science 72: 558-567.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33: 411-521.

Southall, B. L., J.J. Finneran, C. Reichmuth, P.E. Nachtigall, D.R. Ketten, A.E. Bowles, W.T. Ellison, D.P. Nowacek, and P.L. Tyack. 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals 45: 125-232.

Stadler, J.H., and D.P. Woodbury. 2009. Assessing the effects to fishes from pile driving: Application of new hydroacoustic criteria. Internoise 2009.

Tashmukhambetov, A.M., G.E. Ioup, J.W. Ioup, N.A. Sidorovskaia, and J.J. Newcomb. 2008. Three-dimensional seismic array characterization study: Experiment and modeling. Journal of the Acoustical Society of America 123: 4094–4108.

Tolstoy, M., J. Diebold, L. Doermann, S. Nooner, S.C. Webb, D.R. Bohnenstiehl, T.J. Crone, and R.C. Holmes. 2009. Broadband calibration of the R/V Marcus G. Langseth four-string seismic sources. Geochemistry Geophysics Geosystems 10: 1-15.

Urick, R.J. 1979. Sound Propagation in the Sea. Washington, D.C.: Idle Time Books.

Urick, R.J. 1983. Principles of Underwater Sound. New York, New York: McGraw-Hill Book Company.

Ward, W.D. 1960. Recovery from high values of temporary threshold shift. Journal of the Acoustical Society of America 32: 497-500.

Ward, W.D., A. Glorig, and D.L. Sklar. 1958. Dependence of temporary threshold shift at 4 kc on intensity and time. Journal of the Acoustical Society of America 30: 944-954.

Ward, W.D., A. Glorig, and D.L. Sklar. 1959. Temporary threshold shift from octave-band noise: Application to damage-risk criteria. Journal of the Acoustical Society of America 31: 522-528.

Watson, L., E. Dunham, and S. Ronen. 2016. Numerical modeling of seismic airguns and low-pressure sources. Pages 219-224 in SEG Technical Program Expanded Abstracts. Tulsa, Oklahoma: Society of Exploration Geophysicists

Yost, W.A. 2007. Fundamentals of Hearing: An Introduction. New York: Academic Press.

Zampolli M., M.J.J. Nijhof, C.A.F. De Jong, M.A. Ainslie, E.H.W. Jansen, and B.A.J. Quesson. 2013. Validation of finite element computations for the quantitative prediction of underwater noise from impact pile driving. Journal of the Acoustical Society of America 133**:** 72–81.