Apache

May 24, 2012

Brian D. Hopper
Office of Protected Resources,
National Marine Fisheries Service
1315 East West Highway
Silver Spring, MD 20910

RE: Apache Alaska Corporation
2012 Sound Source Verification Results

Dear Mr. Hopper,

Please find enclosed a copy of the Sound Source Acoustic Measurements report conducted by JASCO Applied Sciences in May of 2012. JASCO submitted the preliminary report of the Sound Source Verification (SSV) test to Apache on May 14, 2012. The preliminary results indicated the distance to the 160 dB disturbance threshold in nearshore waters (<10 meters) is 5 km, and the offshore disturbance threshold increased from the pre-field estimate of 6.41 km to 9.5 km for the 2400 cui air gun array. The report was reviewed and discussed between JASCO and Apache (and contractors) for several days. However, Apache implemented immediate changes to the monitoring program, including:

- Expanded daily aerial survey conducted from Shirleyville/Tyonek north to the southern portion of the Susitna Flats and south to McArthur River within 1 mile of the shoreline;
- Land-based observation using big-eyes from Shirleyville or Tyonek dock;
- Spatial positioning of the mitigation vessel (M/V Dreamcatcher) to visually and acoustically monitor a larger area north of the seismic acquisition patch; and
- Standard mitigation/monitoring, such as 2 PSOs on each source vessel (M/V Arctic Wolf, M/V Peregrine Falcon), 2 PSOs on the Dreamcatcher during all daytime operations; and 2 acoustic monitors on the Dreamcatcher during all night operations.

On May 16, 2012, a teleconference between Apache (and contractors) and yourself was held to discuss the results. Apache was granted approval to continue review of the JASCO report and continue the existing monitoring program with the increased measures listed above.

On May 16, 2012, JASCO submitted a second SSV report with monitoring recommendations. This report was accepted by Apache (and contractors) on May 22, 2012.

Apache is submitting the final SSV results to NMFS with the following expanded monitoring and mitigation measures to ensure full coverage of the 160 dB monitoring zone.

- Continuation of the 2 PSOs on each source vessel, 2 PSOs on the mitigation vessel during daytime operations; and 2 acousticicians on the mitigation vessel during nighttime operations.
- Big eye binoculars will be added to the Arctic Wolf and the Dreamcatcher to allow for monitoring at greater distances from the source vessel and the mitigation vessel.
- Aerial flights will continue daily (as safety and weather allow) 10 km on either side of the planned operations (typically this area is larger due to flying river to river).

- Two land-based observers at adequate height with big eye binoculars (as safety allows considering bear activity). The two observers will be stationed opposite from the mitigation vessel (e.g., if mitigation vessel is to the north of the air gun array, the land-based would be to the south).
- As operations move into offshore waters, the practicality of the land-based observers and aerial overflights will be assessed and implemented accordingly.

Please do not hesitate to contact Lisa Parker of my staff at (907) 792-7302 if you have any questions or concerns regarding this submittal.

Sincerely,

John L. Hendrix
General Manager

Cc: Mandy Migura, NMFS

JASCO APPLIED SCIENCES

# Sound Source Acoustic Measurements for Apache's 2012 Cook Inlet Seismic Survey

*Submitted to:*
Fairweather LLC for
Apache Corporation

*Authors:*
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2012 May 16

P001134-006
Version 2.0

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# 1. Introduction

## 1.1. Study Overview

This report presents initial results of an underwater acoustic study designed to characterize the sound emissions of seismic sound sources involved in Apache's 2012 Seismic Survey in Cook Inlet. The acoustic measurement study was performed by JASCO Applied Sciences, under contract to SA Exploration, to measure underwater sound pressure levels (SPLs) as a function of distance, frequency and direction from airgun array sound sources deployed for Apache's survey. The acoustic measurements were conducted to satisfy the requirements in Apache's Incidental Harassment Authorization (IHA).

JASCO performed acoustic measurements using its Ocean Bottom Hydrophone (OBH) systems to measure underwater SPLs produced by the program's three airgun array configurations (440, 1200, and 2400 $in^3$) and a 10 $in^3$ mitigation gun. The measurements were carried out from 6 – 8 May, 2012. The data recorders were retrieved and data downloaded by 16:00 9 May, 2012 Alaska Daylight Time.

The primary goals of the acoustic measurements were as follows:

1. To measure the 190, 180, and 160 dB re 1 μPa (rms) SPL distances in the broadside and endfire directions from the full airgun arrays and 10 $in^3$ mitigation gun.
2. To compare the distances from the measurements with the corresponding distances in the IHA.

This report contains an explanation of the approach used to measure threshold distances for impulsive sound levels between 190 and 160 dB re 1 μPa (rms) in 10 dB steps for each source type.

# 2. Test Seismic Survey Description

## 2.1. Survey Location and recorder geometry

The test seismic survey program was carried out on the north shore of Cook Inlet at Beshta Bay. Figure 1 provides a map of the test survey area with the survey lines and acoustic monitoring stations indicated. Two separate track lines were defined to enable sound levels to be measured for source locations in shallow water (Track 1) and in deeper water (Track 2). The water depth along Track 1 is nearly constant, but there is a transition from deeper to shallower bathymetry along Track 2. Figure 2 below shows the bathymetry along the tracks during source vessel transits while the 2400 $in^3$ array was being measured. This figure illustrates the relative water depths along the tracks but the actual water depths varied with the tide cycle.

Sound levels were recorded using OBH-A through OBH-D (red diamonds on map) while the sources transited Track 1. The OBHs were oriented perpendicular to the source track at ranges extending toward the center of Cook Inlet. After measurements for Track 1 were complete, the OBHs were retrieved and redeployed at stations OBH-E through OBH-G for Track 2 measurements. In this case the OBHs were oriented along a line that extended toward shore.

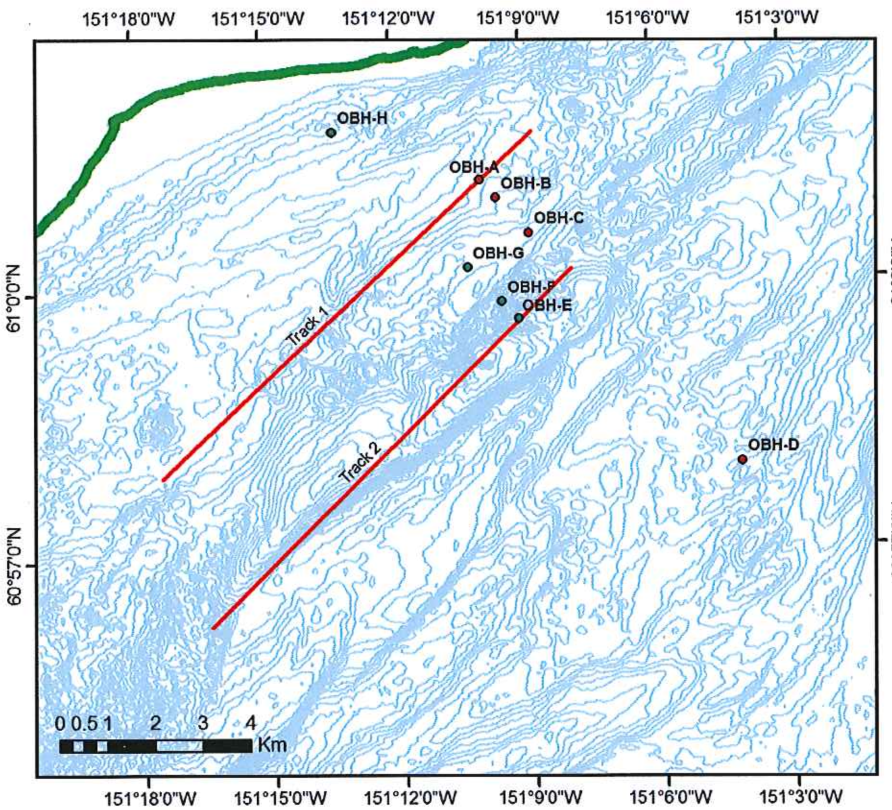


Figure 1. Map of the two acoustic survey lines and OBH locations.

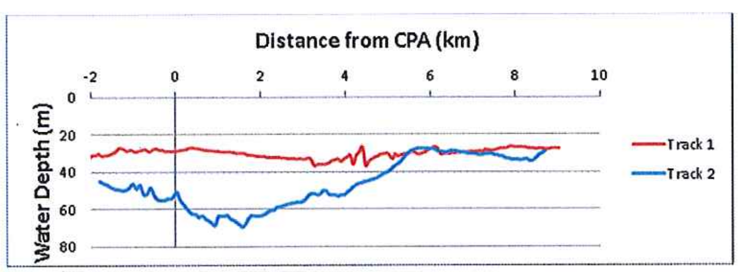


Figure 2: Water depth values along Track 2 measured during a single transit of the source vessel.

## 2.2. Source Types

Four airgun array configurations were measured and are described below. These included a 2400 in$^3$ array, a 1200 in$^3$ sub-array, a 440 in$^3$ array and a 10 in$^3$ mitigation gun.

### 2.2.1. Seismic Airguns

The 2400 in$^3$ airgun array consisted of two 1200 in$^3$ sub-arrays, each having four pairs of 150 in$^3$ airguns. A single 1200 in$^3$ sub-array is shown in Figure 3. The 2400 in$^3$ airgun array was configured as illustrated in Figure 4 with the two sub-arrays separated horizontally by 4.6m. The figure shows only 12 airguns because the sub-arrays contain a pair of airguns suspended below the middle pairs (and hence not visible in these plan views). The sub-arrays were towed at 3 m depth.

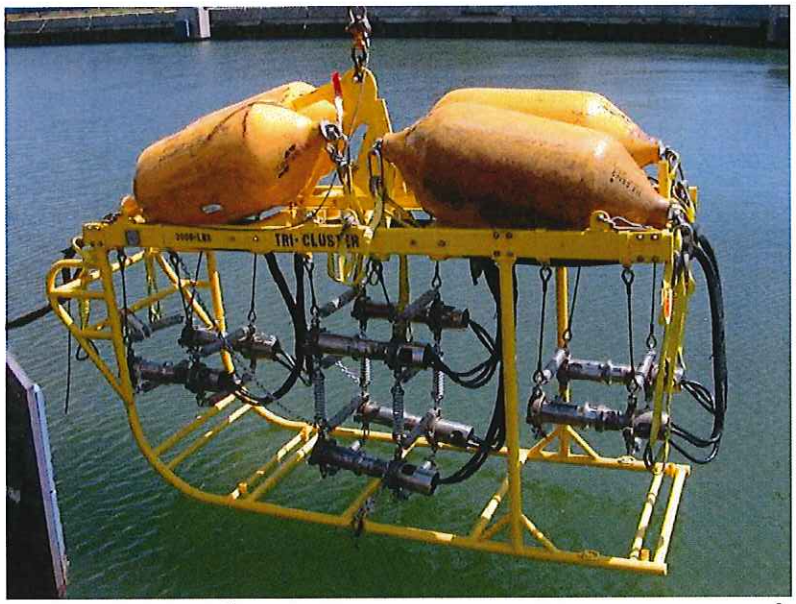

Figure 3. A 1200 in$^3$ tri-cluster sub-array consisting of eight 150 in$^3$ airguns. The 2400 in$^3$ array consisted of two identical 1200 in$^3$ tri-clusters separated horizontally by 4.6 m.

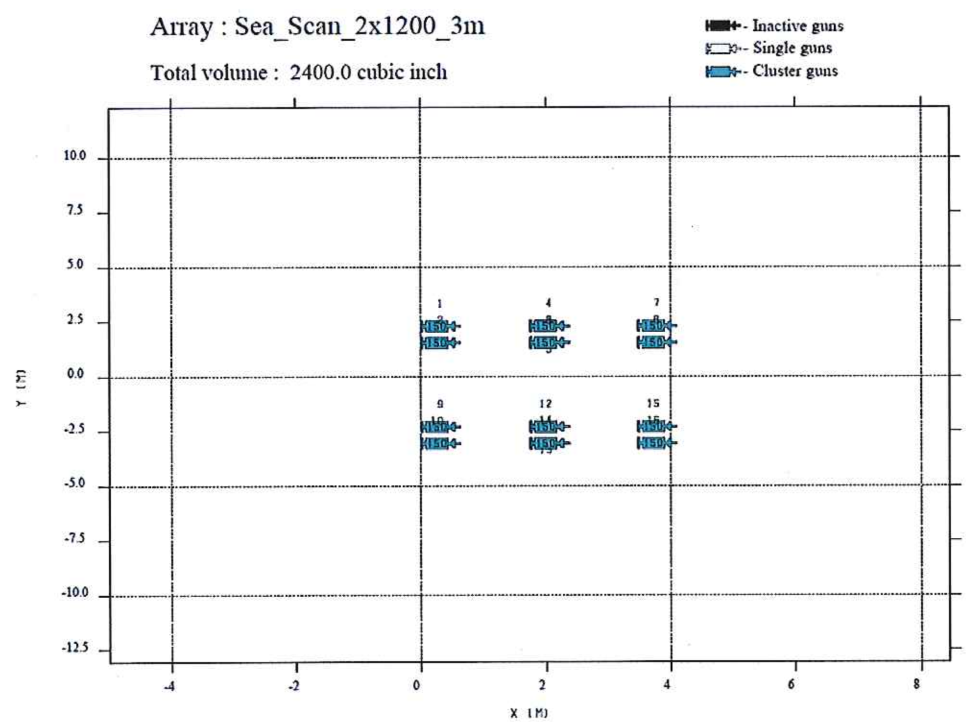


Figure 4. Geometry layout of 2400 in$^3$ array. Tow depth is 3.0 m; the volume of each airgun is indicated in cubic inches. This array consists of two 1200 in$^3$ sub-arrays separated horizontally by 4.6 m.

Additionally, a smaller 440 in$^3$ array (Figure 5, left) that consisted of two 70 in$^3$ and two 150 in$^3$ airguns was also measured. The 150 in$^3$ airguns were positioned at the front of the array and the 70 in$^3$ airguns were 1.2 m behind. The pairs of airguns were separated port/starboard by 1 m. The 440 in$^3$ array was towed at 2 m depth. A single 10 in$^3$ gun (Figure 5, right) was also measured and was towed at 1 m depth.


Figure 5 The 440 in$^3$ array sitting on the back deck before deployment (left) and the 10 in$^3$ mitigation airgun as it was being deployed.

### 2.2.2. Pre-season Estimates of Sound Threshold Radii

Table 1 shows the pre-season threshold radii as indicated in the IHA permit application for the 440 in³ airgun array, the 2440 in³ airgun array, and 10 in³ mitigation gun. Radii for the 1200 in$^3$ sub-array were not listed in the IHA.

Table 1: Pre-season estimates of sound threshold radii.

| $SPL_{rms90}$ (dB re 1 µPa) | 2400 in³ Airgun Array (Nearshore) | 2400 in³ Airgun Array (Offshore) | 440 in³ Airgun Array | Mitigation Gun (10 in³) |
|---|---|---|---|---|
| 190 | 510m | 180m | NA | 10m |
| 180 | 1420m | 980m | NA | 33m |
| 160 | 6410m | 4890m | NA | 330m |

## 3. Acoustic Measurement and Analysis Methods

### 3.1. Measurement Apparatus and Calibration

Underwater sound level measurements were obtained using two deployments of four autonomous Ocean Bottom Hydrophone (OBH) recorder systems (see Figure 6). The OBH units provided high-resolution, digital underwater sound recordings on two channels using two different hydrophone sensitivities. The lower sensitivity channel used a calibrated Reson TC4043 hydrophone with nominal sensitivity -201 dB re V/µPa, and the higher sensitivity channel used a calibrated Reson TC4032 hydrophone with nominal sensitivity -170 dB re V/µPa. The acoustic data were recorded on calibrated Sound Devices 722 24-bit audio hard-drive recorders at 48 kHz sampling rate for Track 1 measurements and at 96 kHz for Track 2 measurements. The sample rate was increased to 96 kHz during the second set of deployments such that sounds from a high-frequency TZ/OBC Transponder could be measured. Each time the recorders were retrieved, the data were transferred to external hard drives for backup.

The OBH systems were calibrated using a GRAS 42AC pistonphone precision sound source, which generated a 250 Hz reference tone with amplitude accurate to within ± 0.08 dB. The tone level was played directly to the hydrophone sensors using a specialized adapter. Calibrations were performed in the field immediately prior to each deployment and immediately upon each retrieval. The pistonphone reference signal was recorded by the digital recorders and was later analyzed to provide end-to-end system calibration of hydrophone, amplifiers and digitization. The pressure sensitivity obtained from the pistonphone calibration was used in the subsequent data analysis for determination of airgun sound levels.

The OBHs were fitted with floats and an acoustic release. Chain links (240 lbs total weight) were used as ballast to sink the recorders on deployment. Upon recovery, a transducer was used to trigger the acoustic release, releasing each recorder from its ballast. The recorders floated to the surface and were retrieved using a mooring hook and crane.

Global Positioning System (GPS) coordinates of deployment locations were obtained with a Garmin handheld GPS and are accurate to within 5 m. Time-stamped source and vessel navigation data were provided by the navigation team on board the source vessel.

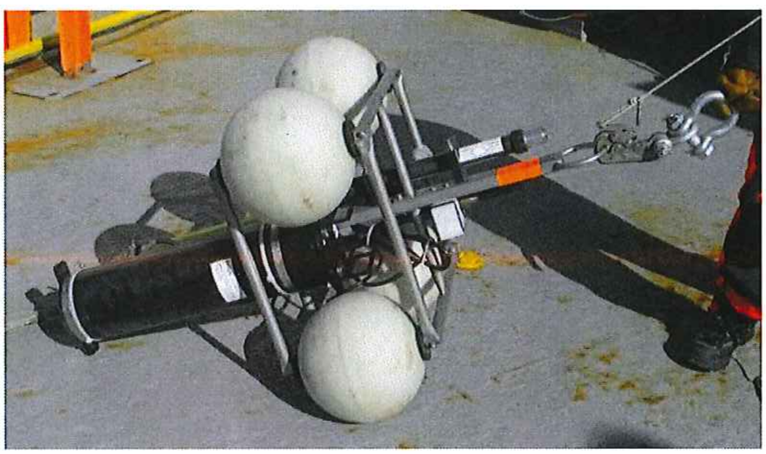

Figure 6. Photograph of a JASCO Ocean Bottom Hydrophone (OBH) recorder.

## 3.2. Measurement Procedures

Deployment details for each OBH are listed in Table 2. Table 3 lists dates of operation and the track line transited for each measured sound source.

Table 2. OBH location coordinates (WGS-84) and deployment and retrieval times for the acoustic measurements. Water depths indicate the depth at time of deployment.

| Station | Deployment Date and Time (AKDT) | Retrieval Date and Time (AKDT) | Latitude | Longitude | Water Depth (m) | Range from Source Track (m) |
|---|---|---|---|---|---|---|
| OBH-A (S-02) | 6 May, 07:29 | 7 May, 14:09 | 61°01.159'N | 151°09.998'W | 17.2 | 0 |
| OBH-B (S-05) | 6 May, 07:15 | 7 May, 14:31 | 61°00.984'N | 151°09.600'W | 20.6 | 500 |
| OBH-C (S-01) | 6 May, 06:56 | 7 May, 14:50 | 61°00.554'N | 151°08.854'W | 29.4 | 1500 |
| OBH-D (S-03) | 6 May, 06:21 | 7 May, 15:30 | 60°57.978'N | 151°04.108'W | 26.4 | 8000 |
| OBH-E (S-03) | 7 May, 18:36 | 9 May, 06:04 | 60°59.586'N | 151°09.184'W | 52.1 | 0 |
| OBH-F (S-05) | 7 May, 18:46 | 9 May, 06:31 | 60°59.798'N | 151°09.596'W | 56.7 | 500 |
| OBH-G (S-01) | 7 May, 18:55 | 9 May, 06:50 | 61°00.195'N | 151°10.356'W | 33.0 | 1500 |
| OBH-H (S-02) | 7 May, 19:19 | 9 May, 07:25 | 61°01.748'N | 151°13.360'W | 15.8 | 5500 |

Table 3. Sound sources monitored during Apache's 3D seismic survey program, 6 – 9 May, 2012. Dates are in AKDT.

| Source | Start Date (2012) and Time (AKDT) | End Date (2012) and Time (AKDT) | acoustic Track |
|---|---|---|---|
| 10 $in^3$ airgun | 6 May, 09:54 | 6 May, 12:10 | Track 1 |
| 1200 $in^3$ airgun array | 6 May, 17:34 | 6 May, 18:23 | Track 1 |
| 2400 $in^3$ airgun array | 6 May, 19:50 | 6 May, 21:05 | Track 1 |
| 440 $in^3$ airgun array | 7 May, 09:37 | 7 May, 13:09 | Track 1 |
| 440 $in^3$ airgun array | 7 May, 20:43 | 8 May, 03:15 | Track 2 |
| 1200 $in^3$ airgun array | 8 May, 08:22 | 8 May, 10:49 | Track 2 |
| 10 $in^3$ airgun | 8 May, 14:59 | 8 May, 16:01 | Track 2 |
| 2400 $in^3$ airgun array | 8 May, 16:43 | 8 May, 17:42 | Track 2 |

## 3.3. Data Analysis Procedures

### 3.3.1. SPL Threshold Radii

Acoustic data were analyzed using custom processing software, to determine peak and *rms* SPLs and sound exposure levels (SELs) versus range from the airgun arrays and explosive shots. The data processing steps were as follows:

1. Airgun pulses (or explosive shots) in the OBH recordings were identified using automated detection algorithm.
2. Waveform data were converted to units of µPa using the calibrated hydrophone sensitivity of each OBH system.
3. For each pulse/shot, the distance to the airgun array was computed from the GPS deployment coordinates of the OBH systems and the time referenced navigation logs of the survey vessel.
4. The airgun pulses were processed to determine peak sound pressure level (Peak SPL), 90% *rms* sound pressure level ($SPL_{rms90}$) and sound exposure level (SEL).

In order to estimate distances to the different *rms* SPL threshold levels, the SPL data were fit to an empirical propagation loss curve of the following form:

$$RL = SL - A\log_{10} R - BR, \text{ or} \quad (1)$$

$$RL = SL - A\log_{10} R \quad (2)$$

where $R$ is the horizontal range from the source to the OBH, $RL$ is the received sound level, $SL$ is the estimated source level term, $A$ is the geometric spreading loss coefficient and $B$ is the absorptive loss coefficient. This equation was fit to the SPL data by minimizing (in the least-squares sense) the difference between the trend line and the measured level-range samples. In order to provide precautionary estimates of the threshold radii, the best fit line was shifted upwards (by increasing the constant $SL$ term) so that the trend line encompassed 90% of all the data. The 90$^{th}$ percentile best-fit values for $SL$, $A$, and $B$ are shown in the SPL plot annotations in the following sections.

The empirical fits for the endfire levels along the offshore line (Track 2) were restricted to measurements at ranges less than 5km to avoid the influence of the site-specific reduction in sound levels resulting from the shoaling bathymetry along the track (see Figure 2). Restricting the measurements to ranges less than 5km excluded the influence from absorptive loss effects that tend to be observed at longer ranges, and the threshold radii were calculated from extrapolated linear-fits in the form of Equation (2) above.

# 4. Results

## 4.1. 10 in$^3$ Mitigation Gun

Peak SPL, 90% rms SPL and SEL for each shot along the nearshore (track 1) and offshore (track 2) lines were computed from acoustic data recorded on OBHs A-D and E-H, respectively. The left panel of Figure 7 shows sound levels from the 10 in³ mitigation gun versus slant range measured in the endfire direction on OBH-A as the source transited the nearshore line (Track 1). This plot only shows levels received within 200 m of the source due to the low signal-to-noise ratio at longer measurement ranges for this track. Corresponding levels for the offshore (Track 2) line are shown in the panel on the right as recorded on OBH-E. Sound levels shown were recorded on the more sensitive TC4032 hydrophones unless clipping or non-linear effects near saturation were observed. For those pulses, sound levels are from the less sensitive TC4043 hydrophone. Tables 4 and 5 list ranges to several rms SPL thresholds for each of the fits in Figure 7.

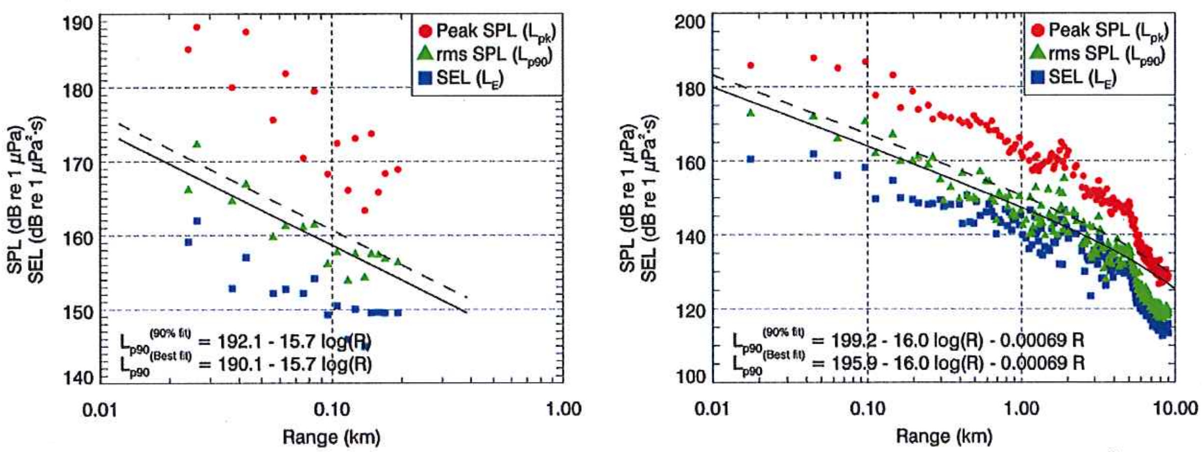


Figure 7: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 10 in$^3$ mitigation airgun pulses in the endfire direction for the nearshore line (left) and offshore track (right). Solid line is best fit of the empirical function to SPL$_{rms90}$ values. Dashed line is the best-fit adjusted to exceed 90% of the SPL$_{rms90}$ values.

Table 4: Threshold radii for the 10 in$^3$ mitigation airgun from the nearshore line as determined from empirical fits to SPL$_{rms90}$ versus distance data in Figure 7 (left).

| SPL$_{rms90}$ Threshold (dB re 1 μPa) | Range (m) in endfire direction Best fit | 90$^{th}$ percentile fit |
|---|---|---|
| 190 | <10 | <10 |
| 180 | <10 | <10 |
| 170 | 19 | 26 |
| 160 | 83 | 110 |

*Extrapolated beyond measurement range.

Table 5: Threshold radii for the 10 in$^3$ mitigation airgun from the offshore line as determined from empirical fits to SPL$_{rms90}$ versus distance data in Figure 7 (right).

| SPL$_{rms90}$ Threshold (dB re 1 μPa) | Range (m) in endfire direction Best fit | 90$^{th}$ percentile fit |
|---|---|---|
| 190 | <10 | <10 |
| 180 | <10 | <10 |
| 170 | 42 | 67 |
| 160 | 180 | 280 |

## 4.2. 440 in$^3$ Airgun Array

Peak SPL, 90% rms SPL and SEL for each shot along the nearshore (track 1) and offshore (track 2) lines were computed from acoustic data recorded on OBHs A-D and E-H, respectively. Figure 8 shows sound levels from the 440 in³ airgun array versus slant range measured in the endfire and broadside directions for the nearshore line (track 1). Figure 9 shows corresponding levels for the offshore (track 2) line. Sound levels are from the more sensitive TC4032 hydrophones unless clipping or non-linear effects near saturation were observed. For those pulses, sound levels are from the less sensitive TC4043 hydrophone. A 25 Hz high pass filter was applied to recordings on OBH D (track 1) prior to SPL calculations to isolate airgun sounds from flow noise. Tables 6 and 7 list ranges to several rms SPL thresholds for each of the fits in Figures 8 and 9.

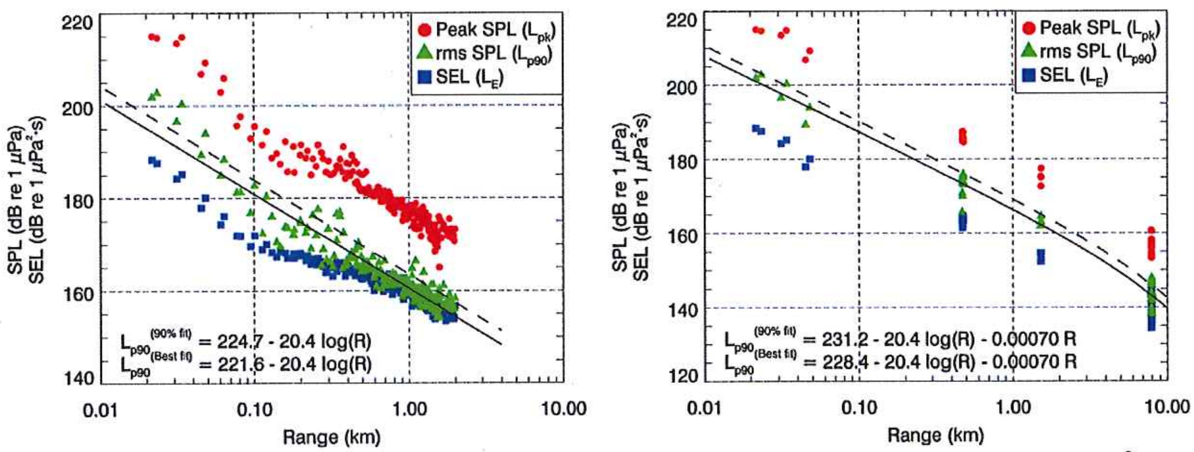


Figure 8: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 440 in$^3$ airgun array pulses in the endfire (left) and broadside (right) directions measured for the nearshore line (track 1). Solid line is best fit of the empirical function to $SPL_{rms90}$ values. Dashed line is the best-fit adjusted to exceed 90% of the $SPL_{rms90}$ values.

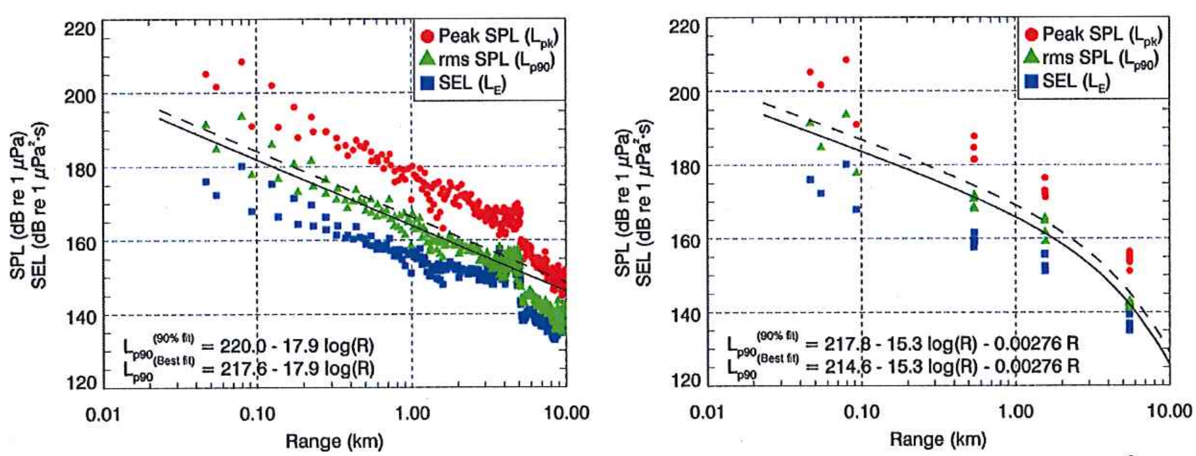


Figure 9: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 440 in$^3$ airgun array pulses in the endfire (left) and broadside (right) directions measured at the offshore line (track 2). Solid line is best fit of the empirical function to $SPL_{rms90}$ values. Dashed line is the best-fit adjusted to exceed 90% of the $SPL_{rms90}$ values. The endfire empirical fit was restricted to measurements at ranges less than 5 km to provide accurate distances to thresholds above 150 dB; data at ranges beyond 5 km are shown for completeness.

Table 6: Threshold radii for the 440 in$^3$ airgun array at the nearshore site as determined from empirical fits to $SPL_{rms90}$ versus distance data in Figure 8.

| $SPL_{rms90}$ Threshold (dB re 1 µPa) | Range (m) in endfire direction Best fit | 90$^{th}$ percentile fit | Range (m) in broadside direction Best fit | 90$^{th}$ percentile fit |
|---|---|---|---|---|
| 190 | 36 | 50 | 75 | 100 |
| 180 | 110 | 160 | 230 | 310 |
| 170 | 340 | 480 | 680 | 920 |
| 160 | 1100 | 1500 | 1900 | 2500 |

Table 7: Threshold radii for the 440 in$^3$ airgun array at the offshore site as determined from empirical fits to $SPL_{rms90}$ versus distance data in Figure 9.

| $SPL_{rms90}$ Threshold (dB re 1 µPa) | Range (m) in endfire direction Best fit | 90$^{th}$ percentile fit | Range (m) in broadside direction Best fit | 90$^{th}$ percentile fit |
|---|---|---|---|---|
| 190 | 35 | 47 | 40 | 64 |
| 180 | 130 | 170 | 170 | 260 |
| 170 | 460 | 630 | 630 | 910 |
| 160 | 1700 | 2300 | 1800 | 2300 |

## *4.3. 1200 in$^3$ Airgun Array*

Peak SPL, 90% rms SPL and SEL for each shot on the nearshore (track 1) and offshore (track 2) lines were computed from acoustic data recorded on OBHs A-D and E-H, respectively. Figure 12 shows sound levels from the 1200 in³ airgun array versus slant range measured in the endfire and broadside directions for the nearshore line (track 1). Figure 13 shows corresponding levels for the offshore (track 2) line. Sound levels are from the more sensitive TC4032 hydrophones unless clipping or non-linear effects near saturation were observed. For those pulses, sound levels are from the less sensitive TC4043 hydrophone. Tables 10 and 11 list ranges to several rms SPL thresholds for each of the fits in Figures 12 and 13. The radius to the 160 dB threshold is derived from a linear fit to the data at ranges less than 5 km (see Section 3.3). This radius is expected to exceed that which would be derived from longer range measurements with absorptive loss effects and likely overestimates the true radius to the 160 dB threshold.

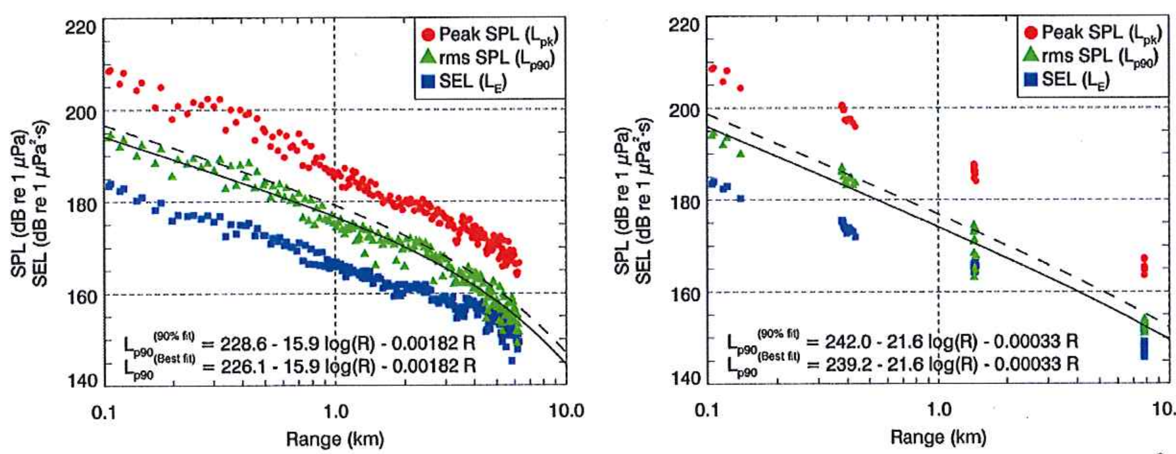


Figure 10: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 1200 in$^3$ airgun array pulses in the endfire (left) and broadside (right) directions measured at the nearshore sites

(track 1). Solid line is best fit of the empirical function to $SPL_{rms90}$ values. Dashed line is the best-fit adjusted to exceed 90% of the $SPL_{rms90}$ values.

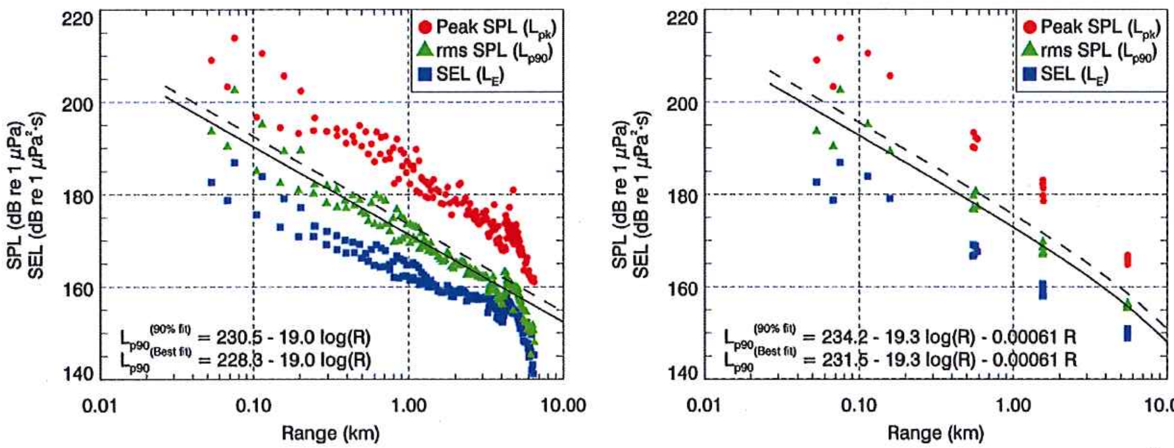


Figure 11: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 1200 $in^3$ airgun array pulses in the endfire (left) and broadside (right) directions measured at the offshore sites (track 2). Solid line is best fit of the empirical function to $SPL_{rms90}$ values. Dashed line is the best-fit adjusted to exceed 90% of the $SPL_{rms90}$ values. The endfire empirical fit was restricted to measurements at ranges less than 5 km to provide accurate distances to thresholds above 160 dB; data at ranges beyond 5 km are shown for completeness.

Table 8: Threshold radii for the 1200 $in^3$ airgun array at the nearshore site as determined from empirical fits to $SPL_{rms90}$ versus distance data in Figure 12.

| $SPL_{rms90}$ Threshold (dB re 1 μPa) | Range (m) in endfire direction Best fit | 90$^{th}$ percentile fit | Range (m) in broadside direction Best fit | 90$^{th}$ percentile fit |
|---|---|---|---|---|
| 190 | 180 | 250 | 190 | 250 |
| 180 | 670 | 910 | 540 | 720 |
| 170 | 2000 | 2500 | 1500 | 2000 |
| 160 | 4500 | 5300 | 4000 | 5200 |

Table 9: Threshold radii for the 1200 $in^3$ airgun array at the offshore site as determined from empirical fits to $SPL_{rms90}$ versus distance data in Figure 13.

| $SPL_{rms90}$ Threshold (dB re 1 μPa) | Range (m) in endfire direction Best fit | 90$^{th}$ percentile fit | Range (m) in broadside direction Best fit | 90$^{th}$ percentile fit |
|---|---|---|---|---|
| 190 | 100 | 140 | 140 | 190 |
| 180 | 350 | 460 | 450 | 610 |
| 170 | 1200 | 1500 | 1400 | 1800 |
| 160 | 4000 | 5200 | 3800 | 4900 |

## 4.4. 2400 $in^3$ Airgun Array

Peak SPL, 90% rms SPL and SEL for each shot on the nearshore (track 1) and offshore (track 2) lines were computed from acoustic data recorded on OBHs A-D and E-H, respectively. Figure 12 shows sound levels from the 2400 in³ airgun array versus slant range measured in the endfire and broadside directions for the nearshore line (track 1). Figure 13 shows corresponding levels for the offshore (track 2) line. Sound levels are from the more sensitive TC4032 hydrophones unless clipping or non-linear effects near saturation were observed. For those pulses, sound levels are from the less sensitive TC4043 hydrophone. Tables 10 and 11 list ranges to several rms SPL thresholds for each of the fits in Figures 12 and 13. The measured levels are consistent with acoustic measurements of the 2400 in$^3$ array that were collected in Cook Inlet by JASCO in 2011 (McCrodan et al, 2011). The radius to the 160 dB threshold is derived from a linear fit to the data at ranges less than 5 km (see Section 3.3). This radius is expected to exceed that which would be derived from longer range measurements with absorptive loss effects and likely overestimates the true radius to the 160 dB threshold.

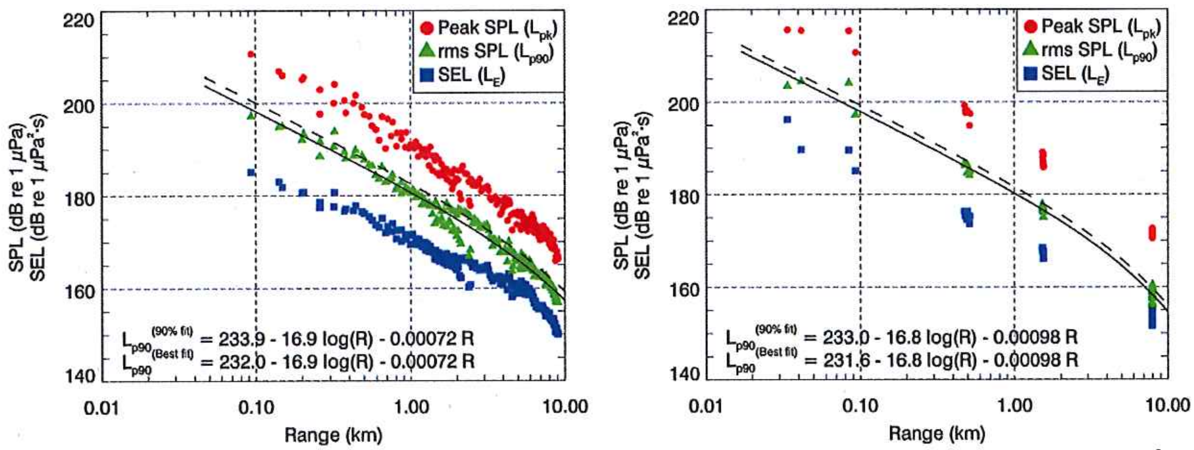


Figure 12: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 2400 in$^3$ airgun array pulses in the endfire (left) and broadside (right) directions measured at the nearshore sites (track 1). Solid line is best fit of the empirical function to $SPL_{rms90}$ values. Dashed line is the best-fit adjusted to exceed 90% of the $SPL_{rms90}$ values.

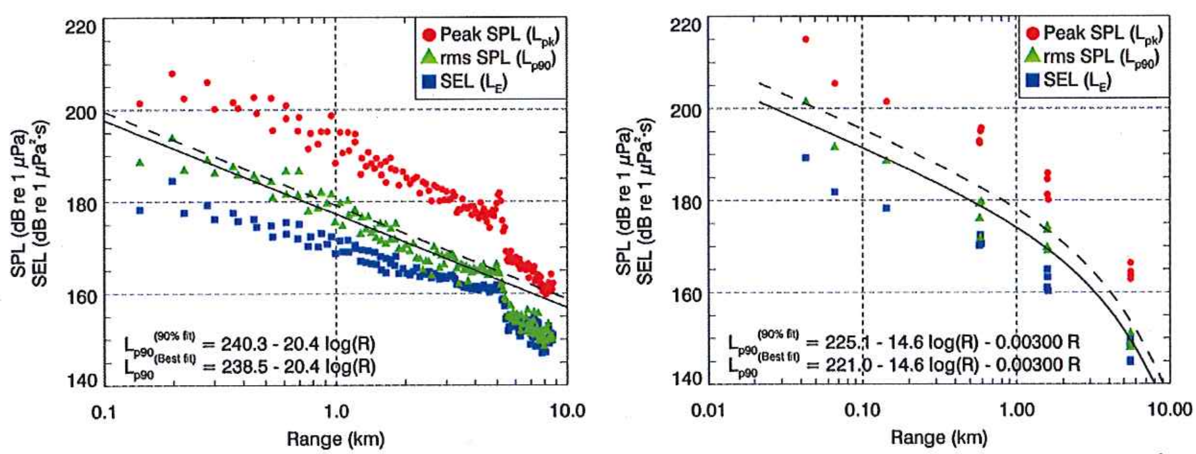


Figure 13: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 2400 in$^3$ airgun array pulses in the endfire (left) and broadside (right) directions measured at the offshore sites (track 2). Solid line is best fit of the empirical function to $SPL_{rms90}$ values. Dashed line is the best-fit adjusted to exceed 90% of the $SPL_{rms90}$ values. The endfire empirical fit was restricted to measurements at ranges less than 5 km to provide accurate distances to thresholds above 150 dB; data at ranges beyond 5 km are shown for completeness.

Table 10: Threshold radii for the 2400 $in^3$ airgun array at the nearshore site as determined from empirical fits to $SPL_{rms90}$ versus distance data in Figure 12.

| $SPL_{rms90}$ Threshold | Range (m) in endfire direction | | Range (m) in broadside direction | |
|---|---|---|---|---|
| (dB re 1 µPa) | Best fit | $90^{th}$ percentile fit | Best fit | $90^{th}$ percentile fit |
| 190 | 300 | 380 | 290 | 350 |
| 180 | 1100 | 1400 | 1030 | 1210 |
| 170 | 3400 | 4100 | 3080 | 3500 |
| 160 | 8200 | 9500 | 7070 | 7770 |

Table 11: Threshold radii for the 2400 $in^3$ airgun array at the offshore site as determined from empirical fits to $SPL_{rms90}$ versus distance data in Figure 13.

| $SPL_{rms90}$ Threshold | Range (m) in endfire direction | | Range (m) in broadside direction | |
|---|---|---|---|---|
| (dB re 1 µPa) | Best fit | $90^{th}$ percentile fit | Best fit | $90^{th}$ percentile fit |
| 190 | 240 | 290 | 120 | 220 |
| 180 | 740 | 910 | 500 | 820 |
| 170 | 2300 | 2800 | 1500 | 2130 |
| 160 | <7100* (> 5295) | <8700* (> 5295) | 3220 | 4080 |

*Extrapolated based on a linear fit to the data at <5km range, excluding absorptive loss effects

# 5. Comparison with Pre-Season Estimates

Pre-season safety radii estimates are included in the IHA for the 10 $in^3$ mitigation airgun and for the 2400 $in^3$ airgun array in inshore and offshore environments. The values for the 2400 $in^3$ array were derived from an acoustic modelling study conducted by JASCO in 2011 for generic model sites (Warner et al, 2011) and those for the 10 $in^3$ were estimated from previous measurements. Tables 12-14 list the pre-season radii predictions and the maximum corresponding measured $90^{th}$ percentile fit distances for the two airgun systems. The ratio of measured to predicted levels is also shown.

The threshold distances for the 10 $in^3$ airgun were consistently less than, or equal to, the pre-season estimates. The measured threshold distance to 160 dB 1 µPa for the 2400 $in^3$ array exceeded the pre-season estimates for both the nearshore and offshore lines.

Table 12. 10 in³ mitigation airgun: Comparison of measurements with pre-season estimated marine mammal safety radii.

| $SPL_{rms90}$ Threshold (dB re 1 µPa) | *Safety Radii (m)* Pre-season Estimated | 90th Percentile Measured Nearshore | 90th Percentile Measured Offshore | Nearshore Ratio (%) | Offshore Ratio (%) |
|---|---|---|---|---|---|
| 190 | 10 | 10 | 10 | 100 | 100 |
| 180 | 33 | 10 | 10 | 30 | 30 |
| 160 | 330 | 110 | 280 | 33 | 85 |

Table 13. 2400 in³ airgun array: Comparison of measurements with pre-season estimated **nearshore** marine mammal safety radii. Measured distances are maximized over the endfire and broadside directions.

| $SPL_{rms90}$ Threshold (dB re 1 µPa) | *Safety Radii* Pre-season Estimated (from IHA) | 90th Percentile Measured | Ratio (%) |
|---|---|---|---|
| 190 | 510 | 380 | 75 |
| 180 | 1420 | 1400 | 99 |
| 160 | 6410 | 9500 | 148 |

Table 14. 2400 in³ airgun array: Comparison of measurements with pre-season estimated **offshore** marine mammal safety radii. Measured distances are maximized over the endfire and broadside directions.

| $SPL_{rms90}$ Threshold (dB re 1 µPa) | *Safety Radii* Pre-season Estimated (from IHA) | 90th Percentile Measured | Ratio (%) |
|---|---|---|---|
| 190 | 180 | 290 | 161 |
| 180 | 980 | 910 | 93 |
| 160 | 4890 | 8700 | 178 |

# 6. Summary and Conclusions

Table 15 presents the maximum distances to 190, 180 and 160 dB re 1 µPa threshold levels for each of the four airgun array source configuration. These distances are based on the 90th percentile fits as described in Section 3.3.1. They are the maxima over direction (broadside and endfire) and environment (nearshore and offshore sites). The radius to the 160 dB re 1 µPa threshold for the 2400 in³ array is the largest threshold distance and exceeds the pre-season estimate by as much as 48%, although it is substantially less for receivers in shallower (<10 m) water depths.

The maximum threshold radii were measured in the endfire direction from the 2400 in³ array as it transited on the nearshore track in water depths that varied between approximately 25 m and 35 m. The range to the 160 dB re 1 µPa threshold is highly dependent on the water depth in which the source is operating; the endfire-radii (~8700 m) along the offshore track, with depths from 35-65 m, were smaller than those for the inshore track due to increased spreading loss in deeper water.

Measured sound levels decreased as sound propagated from deeper water into shallower water. Examples of this effect include the sharp drop-off of sound levels beyond 5 km range along the offshore track (discussed in Section 3.3.1) and also the reduced levels that were observed on the broadside recorders for the offshore track. These broadside recorders were located in shallower water to approximately 10 m depth on the shoreward side of the survey track. In this case the 160 dB radius was measured at a broadside range of 4080 m, which is less than half the range measured in the endfire direction in deep water and also less than the pre-season estimate.

The lower levels received in shallower water should be considered particularly for effects assessments on belugas, which tend to spend a high proportion of time close to shore and in shallow waters.

Table 15: Maximum threshold distances for the mitigation airgun and three airgun arrays. Distances are maximized over direction and environment and are based on the 90th percentile fits.

| $SPL_{rms90}$ Threshold (dB re 1 µPa) | 90th Percentile Distance (m) | | | |
|---|---|---|---|---|
| | 10 in$^3$ | 440 in$^3$ | 1200 in$^3$ | 2400 in$^3$ |
| 190 | 10 | 100 | 250 | 380 |
| 180 | 10 | 310 | 910 | 1400 |
| 160 | 280 | 2500 | 5300 | 9500* |

*This radius applies to receivers in water depths of approximately 25 m. The radius is substantially reduced for receivers in 10 m water depth, and it slightly reduced for receivers in water depths from 35-65m.

## *6.1. Monitoring Recommendations*

Based on the results summarized above, we recommend that the extent of the exclusion zone for protected species monitoring be dependent on water depth within the zone. Through this definition, the monitoring zone may not be circular about the source. Due to shorter distances to sound thresholds measured in shallow (<10 m) waters, we suggest that the 160 dB re 1 µPa zone be reduced from the values in Table 15 when the zone extends into shallow waters. Table 16 lists the recommended distances based on water depth of the region being observed.

Table 16 Recommended monitoring distances based on water depth.

| Water depth at receiver | Suggested Monitoring Distance |
|---|---|
| Shallow water depths (≤ 10 m) | 5 km |
| Intermediate water depths (10 – 50 m) | 9.5 km |
| Deep water depths (> 50 m) | 8.7 km |

# 7. Literature Cited

McCrodan, A. B., C. McPherson and D.E. Hannay. 2011. *Sound Source Acoustic Measurements for Apache's 2012 Cook Inlet Seismic Survey*: Version 2.0. Technical report for Fairweather LLC and Apache Corporation by JASCO Applied Sciences.

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