Petition for Incidental Take Regulations for Seismic Program Cook Inlet, Alaska in 2015-2020

July 2014

Prepared for
Apache Alaska Corporation
510 L Street, Suite 310
Anchorage, AK 99501

Prepared by

ASRC Energy Services
a subsidiary of Arctic Slope Regional Corporation
Regulatory and Technical Services
3900 C Street Suite 701
Anchorage, Alaska 99503

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Acronyms and Abbreviations

2D	two dimensional
3D	three dimensional
ADF&G	Alaska Department of Fish and Game
Apache	Apache Alaska Corporation
BA	Biological Assessment
BiOp	Biological Opinion
CFR	Code of Federal Regulations
CIMMC	Cook Inlet Marine Mammal Council
dB re 1 µPa	decibel referenced to one microPascal
DGPS/RTK	differential global positioning system/roving units
DPS	Distinct Population Segment
ENP	Eastern North Pacific
ESA	Endangered Species Act
ft	feet
FR	Federal Register
Hz	hertz
in^3	cubic inch
IHA	Incidental Harassment Authorization
INS	Integrated Navigation System
ITR	incidental take regulations
ITS	Incidental Take Statement
JASCO	JASCO Applied Sciences
KABATA	Knik Arm Bridge and Toll Authority
kg	kilogram
kHz	kilohertz
km	kilometer
km^2	square kilometer
lbs	pounds
LOA	Letter of Authorization
m	meter
mi	mile
mi^2	square mile
MMPA	Marine Mammal Protection Act
mph	miles per hour
MTR	Marine Terminal Redevelopment
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NMML	National Marine Mammal Laboratory
NOAA	National Oceanic and Atmospheric Administration
OBRL	Ocean Bottom Receiver Location
OSP	Optimum Sustainable Population
POA	Port of Anchorage
PSO	Protected Species Observer
PTS	permanent threshold shift
rms	root-mean-squared
Seiche	Seiche Measurements Ltd.
SEL	sound energy level
SPL	sound pressure level
SSV	sound source verification
TS	threshold shift

TTS	temporary threshold shift
USBL	Ultra-Short BaseLine
USC	United States Code
USCG	United Stated Coast Guard

1.0 Statement of Request and Context

Apache Alaska Corporation (Apache) hereby petitions the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) to issue regulations for the non-lethal unintentional taking of small numbers of beluga whale (*Delphinapterus leucas*) and other marine mammals incidental to oil and gas exploration seismic operations and all associated activities in Cook Inlet for the period of five years beginning March 1, 2015 extending through February 29, 2020.

Apache plans to acquire seismic surveys throughout Cook Inlet, Alaska over the course of the next several years. Apache applied for and received three Incidental Harassment Authorization (IHAs) to operate a seismic survey in Cook Inlet, in 2012, 2013, and 2014 (77 Federal Register [FR] 27720, 78 FR 12720, 78 FR 80386, 79 FR 13636). Apache's current IHA expires on December 31, 2014.

Apache is requesting that NMFS authorize non-lethal, non-intentional, incidental take of small numbers of marine mammals during oil and gas activities described in this petition within the identified geographic area during the five-year period. These regulations should also identify: permissible methods of non-lethal take; measures to ensure the least practicable adverse impact on these species; and requirements for monitoring and reporting. In conjunction with issuance of the requested incidental take regulations (ITR), Apache further petitions NMFS to engage in consultation under Section 7 of the Endangered Species Act (ESA) and to complete the environmental assessment process under the National Environmental Policy Act (NEPA).

1.1 Future Regulatory Developments

There are areas where future regulatory developments have the potential to affect the ITR requested by this Petition. The following development(s) are likely to occur between the date of the Petition and issuance of the requested ITR:

- New Criteria for Harassment – NMFS is expected to change their methodology for classification of Level A and Level B harassment. Since 1997, NMFS has been using generic sound exposure thresholds to determine when an activity in the ocean that produces sound might result in impacts to a marine mammal such that a take by harassment might occur (70 FR 1871). NMFS is developing new science-based thresholds to improve and replace the current generic exposure level thresholds, but the criteria have not been finalized (Southall et al. 2007). Those guidelines and the suite of mitigation measures adopted for this ITR should be consistent.

2.0 Description of Activities

A detailed description of the specific activity or class of activities that can be expected to result in incidental taking of marine mammals.

2.1 Project Purpose

Apache has acquired over 800,000 acres of oil and gas leases in Cook Inlet since 2010 with the primary objective to explore for and develop oil and gas resources in Cook Inlet. In the spring of 2011, Apache conducted a seismic test program to evaluate the feasibility of using new nodal (no cables) technology seismic recording equipment for operations in Cook Inlet. This test program found and provided important input to assist in finalizing the design of the seismic program in Cook Inlet (the nodal technology was determined to be feasible). Apache began seismic onshore acquisition on the west side of Cook Inlet in September 2011 and offshore acquisition in May 2012 under an IHA issued by NMFS for April 30, 2012 through April 30, 2013 (77 FR 27720). Apache planned to continue acquisition activities under a second IHA application effective March 1, 2013, however Apache did not conduct seismic operations in 2013. Apache continued acquisition activities in Cook Inlet under a third IHA application (79 FR 13626), effective March 4, 2014 through December 31, 2014.

Some marine mammal species in this petition are listed under the ESA, requiring a Biological Assessment (BA) and a Biological Opinion (BiOp). The previous BA and BiOps issued under the IHA process expire in December 2014. Apache recognizes a new BA and BiOp will be required.

Apache proposes to conduct seismic acquisition in the proposed area as shown in Figure 1. The total proposed area encompasses approximately 4,825 square kilometers (km^2) (1,863 square miles [mi^2]) of intertidal and offshore areas. Apache is requesting the area in this petition to allow for maximum operational flexibility in specific areas within Cook Inlet and to allow for the potential to return to areas previously surveyed, if necessary (e.g., to collect 3-dimensional [3D] data where previously only 2D data has been acquired). There are numerous factors that influence the areas that need to be surveyed by Apache, including the geology of the Cook Inlet area, other permitting restrictions (i.e., commercial fishing, subsistence fishing, Alaska Department of Fish and Game [ADF&G] refuges), seismic imaging of leases held by other entities with whom Apache has agreements (e.g., data sharing), overlap of sources and receivers to obtain the necessary seismic imaging data, and general operational restrictions (ice, weather, environmental conditions, marine life activity, etc.). Therefore, Apache is requesting to operate within the proposed area, but intends to survey only a portion of the total area in any given year.

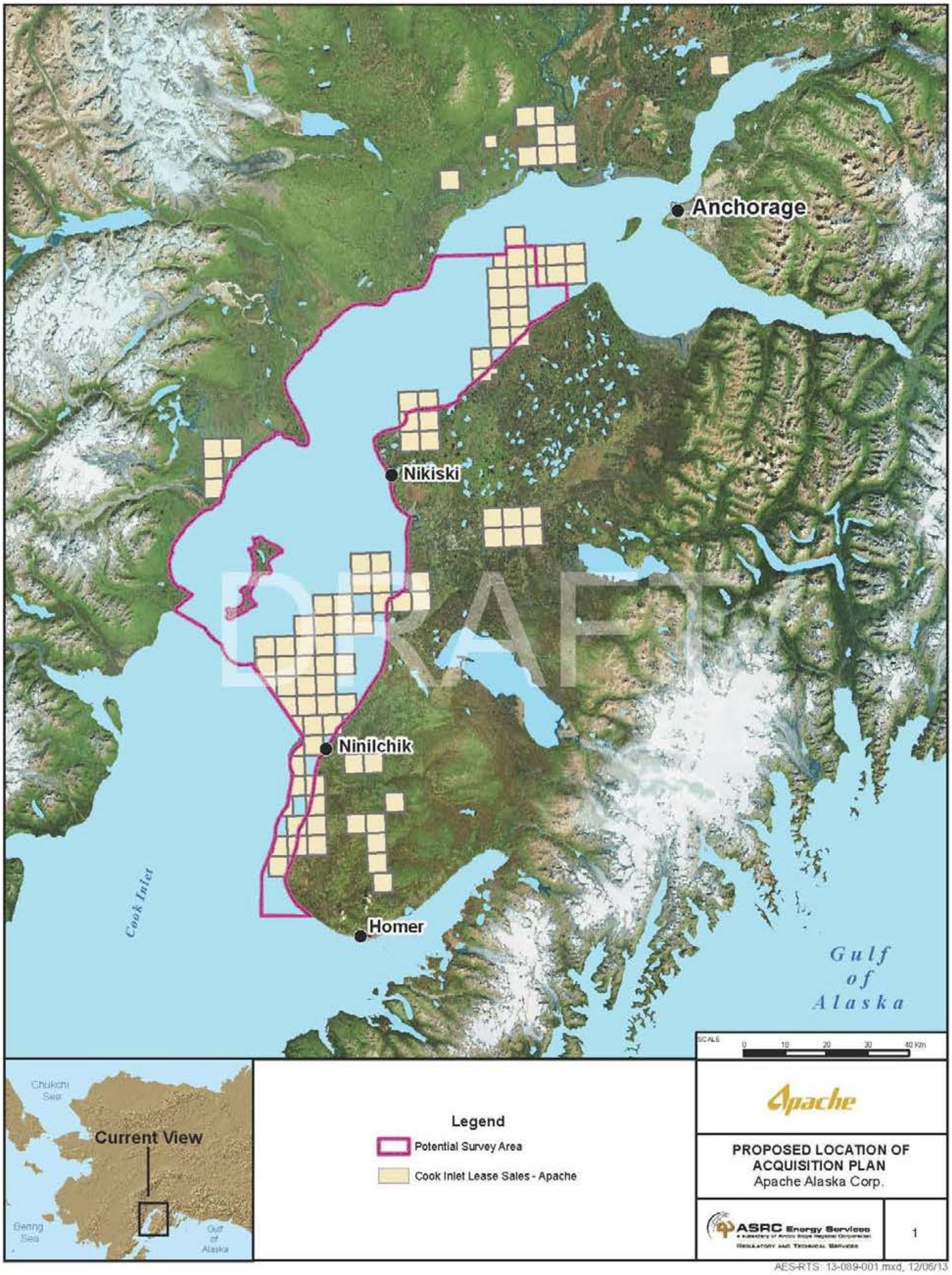


Figure 1. Proposed Location of Acquisition Plan

Each phase of the Apache program encounters land, inter-tidal transition zone, and marine environments. This petition includes activities only in the transition zone and marine environments, as the land-based portion of the program is not anticipated to result in underwater sound levels exceeding NMFS thresholds. In the event that the planned charge depth of 10 m (35 ft) (details in Section 2.2.3.2 Onshore/Intertidal Components) is unattainable due to loose sediments collapsing the bore hole, then a sound source verification (SSV) will be conducted on new land based charge depths to determine if they are within NMFS thresholds. Transition zone and offshore acquisition will include areas below the mean high tide line as depicted in Figure 2. The entire operation will be active 24 hours per day during some, but not all, of the petition's time period; however, airgun activity can only occur during slack tides (low and high) because of the swift tidal currents. The currents during ebb and flood tides limit the operations and safety of the vessels deploying the airguns, as well as decrease the signal-to-noise ratio of the seismic signal to below background levels. In general, there are four slack tides in a 24-hour period; vessels can typically operate approximately 2-3 hours around each slack tide. So the total time of airgun operations in a 24-hour period is 8-12 hours (2-3 hours x 4 slack tides). The actual survey duration will take approximately 160 days over the course of eight to nine months.

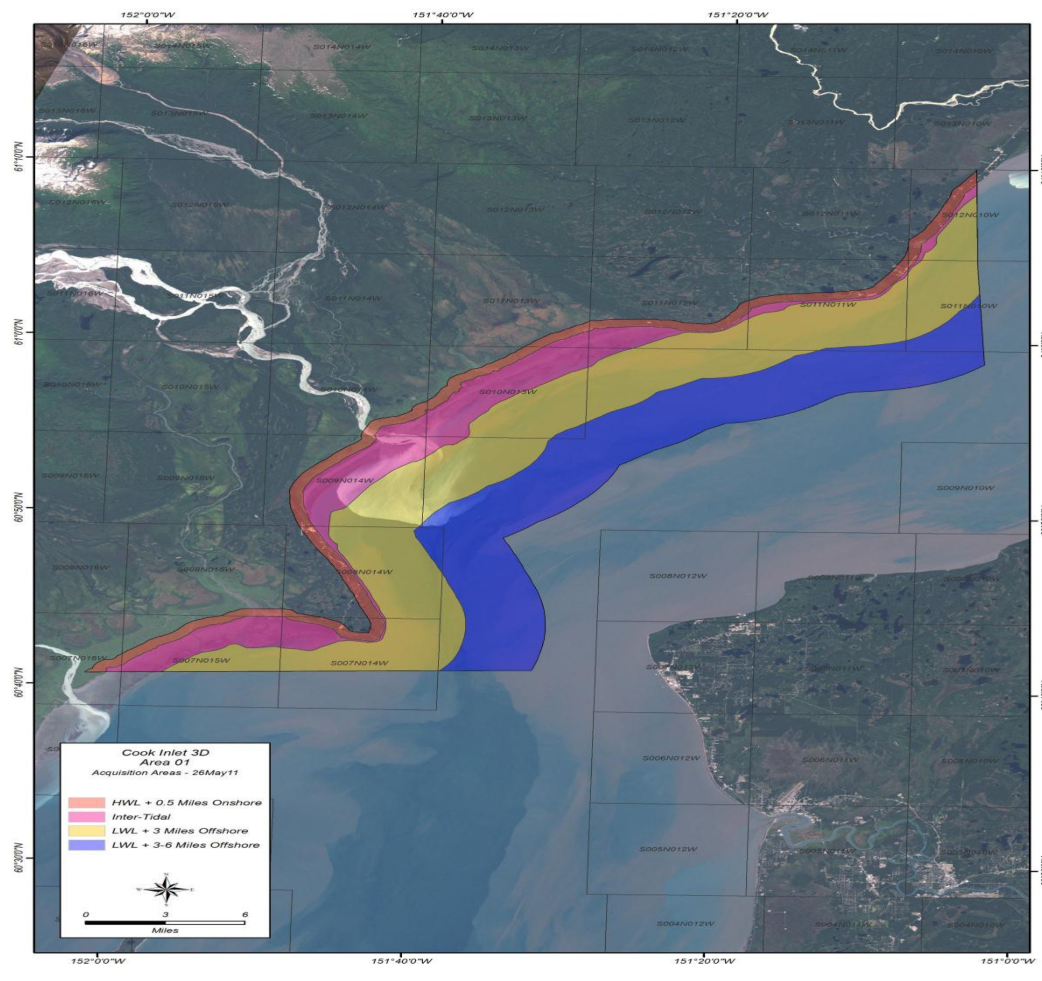


Figure 2. Offshore and Transition Components

Vessels will lay and retrieve the nodal sensors on the sea floor in periods of low current or, in the case of the intertidal area, during high tide over the entire 24-hour period. The offshore and transition zone source effort will include the use of input/output sleeve airguns in two different configurations of arrays: 440 and 2,400 cubic inches [in^3]. Although the 2,400 in^3 airgun array is anticipated to be utilized most frequently, a smaller configuration may be used as was done during the 2014 season. Apache used a 1,760 in^3 airgun array in 2014, but at the time of this petition the data had not been analyzed thus data quality is unknown. For the purposes of this petition the larger 2,400 in^3 airgun array will be described herein. The seismic source vessels expected to be used are the *M/V Peregrine Falcon* and *M/V Arctic Wolf*, or similar vessels. Cable/Nodal deployment and retrieval operations will be supported by three shallow draft vessels (*M/V Miss Diane I*, *M/V Mark Steven*, and *M/V Maxime*), or similar vessels. The mitigation/chase vessel, which will also house the Protected Species Observers (PSOs), will be the *M/V Dreamcatcher*, or a similar vessel. The node re-charging and housing vessel will be the *M/V Westward Wind*, or similar vessel. Two smaller boats will be used for personnel transport and node support in the extremely shallow water in the intertidal area. Water depths for the program will range from 0 to 128 meters (m), (0 to 420 feet [ft]).

2.2 Proposed Program Overview – General

Each phase of the Apache program encounters land, inter-tidal transition zone, and marine environments. The following provides a general overview of the work plan employed for the seismic survey.

2.2.1 Recording System

The recording system is an autonomous system "nodal" (i.e., no cables), made up of at least two types of nodes; one for the land and one for the intertidal and marine environment. For the land operator, a single-component sensor land node will be used (Figure 3); the inter-tidal and marine zone operators, will use a submersible multi-component system made up of three velocity sensors and a hydrophone (Figure 4). These systems have the ability to record continuous data. Inline receiver intervals for the node systems will be 50 m (165 ft). The nodes are deployed in *patches* for the seismic source and deployed for up to 15 days. The deployment length is limited by battery length and data storage capacity.

Figure 3. Onshore Nodal Recording System

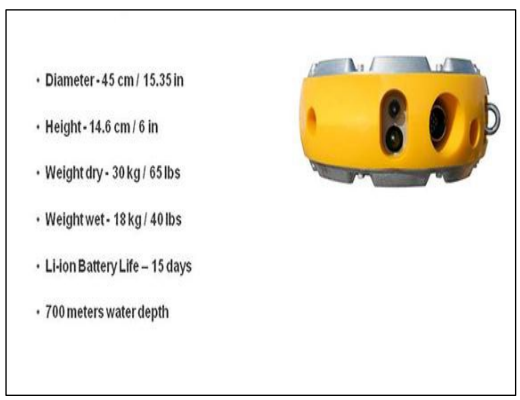


Figure 4. Offshore Nodal Recording System

The geometry methodology that Apache will gather seismic data is called *patch shooting*. This type of seismic survey requires the use of multiple vessels for cable layout/pickup, recording, and sourcing. Operations begin by laying node lines on the seafloor parallel to each other with a node line spacing of approximately 402 m (1,320 ft). Apache's patch will have 6-8 node lines (receivers) that generally run perpendicular to the shoreline for transition zones and parallel to the shoreline for offshore areas. The node lines will be separated by either 402 or 503 m (1,320 or 1,650 ft). Inline spacing between nodes will be 50 m (165 ft). The node vessels will lay the entire patch on the seafloor prior to the airgun activity. Individual vessels are capable of carrying up to 400 nodes. With three node vessels operating simultaneously, a patch can be laid down in a single 24-hour period, weather permitting. A sample transition zone patch is depicted in Figure 5. A sample offshore patch is depicted in Figure 6.

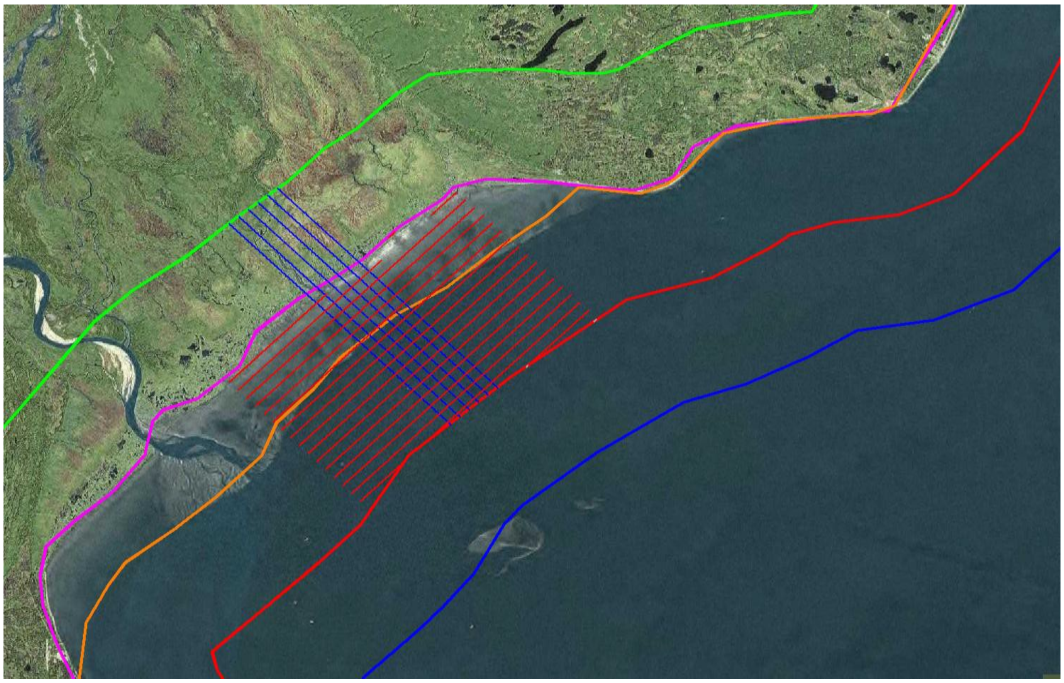


Figure 5. A Single Transition Zone Patch, Six Lines of Nodes (Blue), 16 Source Lines (Red)

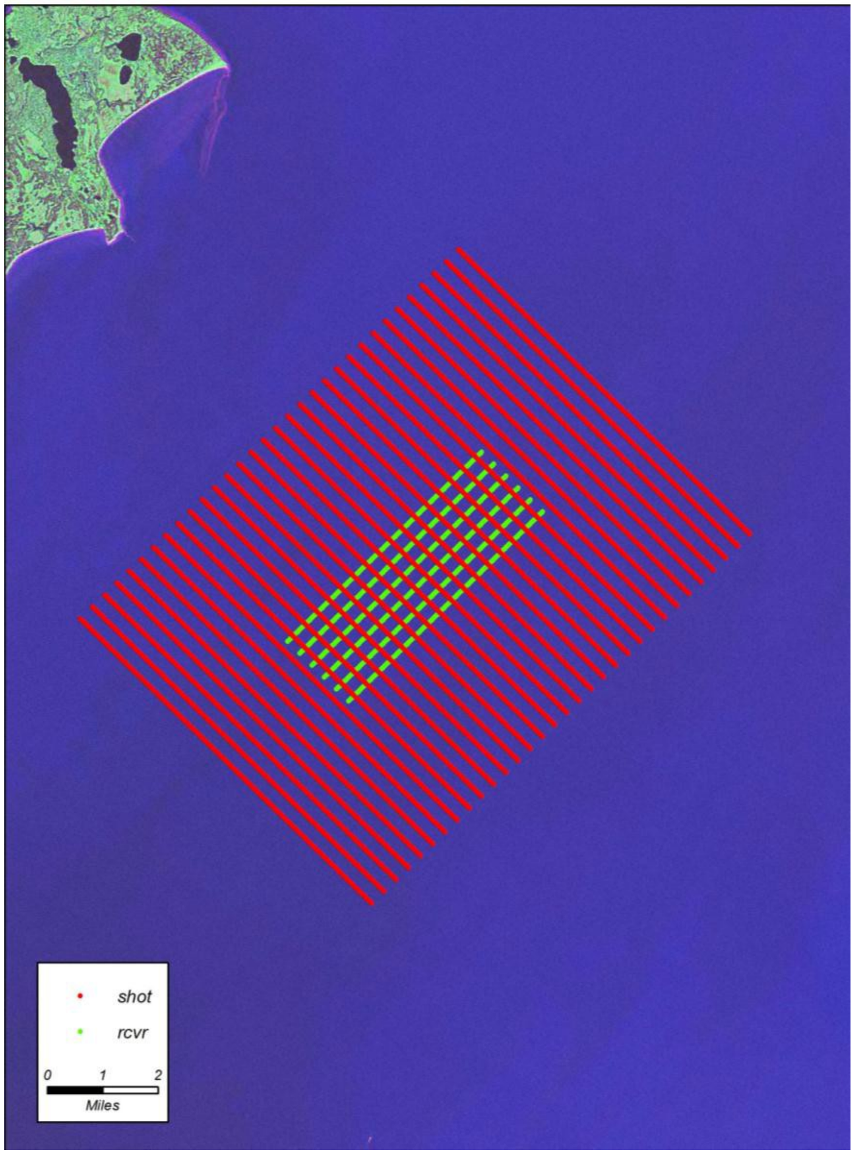


Figure 6. A Single Offshore Patch, Six Lines of Nodes (Green), 16 Source Lines (Red)

As the patches are acquired, the node lines will be moved either side to side or inline to the next patch's location. Figure 7 depicts multiple side to side patches that are acquired individually but when seamed together at the processing phase, create continuous coverage along the coastline.

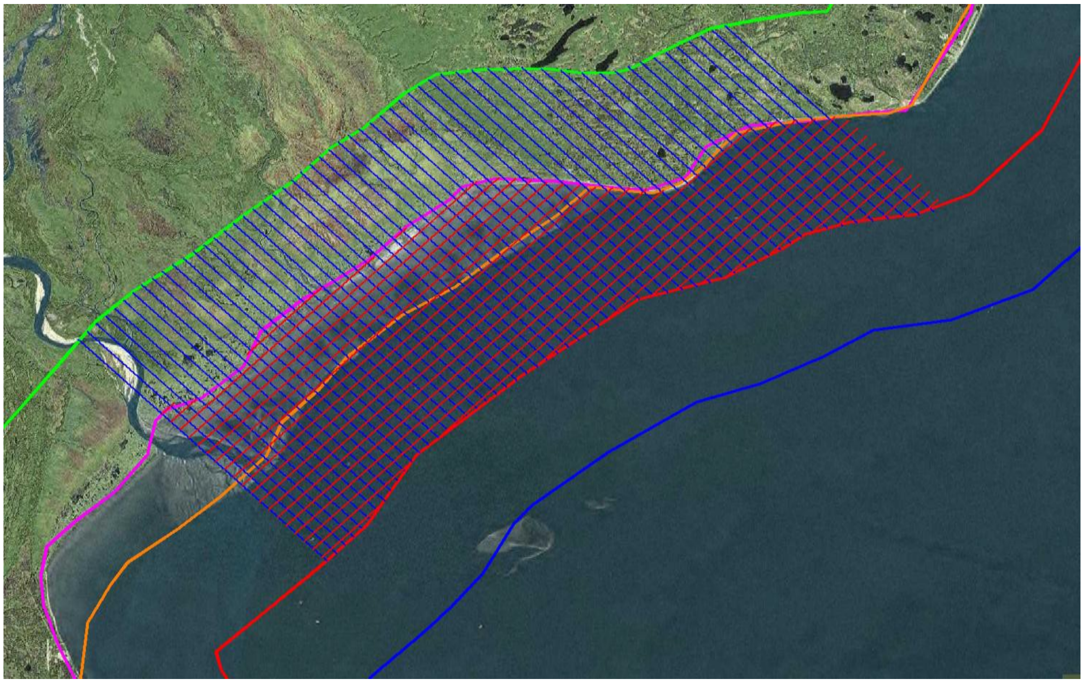


Figure 7. Multiple Intertidal Patches

2.2.2 Sensor Positioning

2.2.2.1 Transition Zone/Offshore Components

Once the nodes are in place on the seafloor, the exact position of each node is required. There are several techniques used to locate the nodes on the seafloor, depending on the depth of the water. In very shallow water, the node positions are either surveyed by a land surveyor when the tide is low, or the position is accepted based on the position at which the navigator has laid the unit.

In deeper water, a technique called Ultra-Short Baseline (USBL) will be used. This technique uses a hull or pole mounted pinger to send a signal to a transponder which is attached to each node. The transponders are coded and the crew knows which transponder goes with which node prior to the layout. The transponder's response (once pinged) is added together with several other responses to create a suite of ranges and bearings between the pinger boat and the node. Those data are then calculated to precisely position the node. In good conditions, the nodes can be interrogated as they are laid out. It is also common for the nodes to be pinged after they have been laid out. The pinger that will be used is a Sonardyne Shallow Water Cable Positioning system. The two instruments used are a Scout USBL Transceiver that operates at a frequency of 33-55 kilohertz (kHz) at a max source level of 188 decibels referenced to one micro Pascal (dB re 1 µPa) at 1 m; and a LR USBL Transponder that operates at a frequency of 35-50 kHz at a source level of 185 dB re 1 µPa at 1 m.

2.2.2.2 Onshore/Intertidal Components

Onshore and intertidal locating of source and receivers will be accomplished with Differential Global Positioning System/roving units (DGPS/RTK) equipped with telemetry radios which will be linked to a base station established on the *M/V Arctic Wolf* or similar vessel. Survey crews will have both helicopter and light tracked vehicle support. Offshore source and receivers will be positioned with an integrated navigation system (INS) utilizing DGPS/RTK link to the land located base stations. The integrated navigation system will be capable of many features that are critical to efficient safe operations. The system will include a hazard display system that can be loaded with known obstructions, or exclusion zones. Typically the vessel displays are also loaded with the day-to-day operational hazards, buoys, etc. This display gives a quick reference when a potential question regarding positioning or tracking arises. In the case of inclement weather, the hazard display can and has been used to vector vessels to safety.

2.2.3 Seismic Source

2.2.3.1 Transition Zone/Offshore Components

Apache will use two synchronized source vessels in time. The source vessels, *M/V Peregrine Falcon* and the *M/V Arctic Wolf* (or similar vessels), will be equipped with compressors and 2,400 in^3 airgun arrays (1,200 in^3, if feasible). The *M/V Peregrine Falcon*, or similar, will be equipped with a 440 in^3 shallow water source which it can deploy at high tide in the intertidal area in less than 1.8 m (6 ft) of water. Source lines are orientated perpendicular to the node lines and parallel to the beach (see red lines on Figure 5). The two source vessels will traverse source lines of the same patch using a shooting technique called *ping/pong*. The ping/pong methodology will have the first source boat commence the source effort. As the first airgun pop is initiated, the second gun boat is sent a command and begins a countdown to pop its guns 12 seconds later than the first vessel. The first source boat would then take its second pop 12 seconds after the second vessel has popped and so on. The vessels try to manage their speed so that they cover approximately 50 m (165 ft) between pops. The objective is to generate source positions for each of the two arrays close to a 50 m (165 ft) interval along each of the source lines in a patch. Vessel speeds range from 2-4 knots. The source effort will average 8-12 hours per day.

Each source line is approximately 12.9 kilometer (km) (8 mile [mi]) long. A single vessel is capable of acquiring a source line in approximately one hour. With two source vessels operating simultaneously, a patch of approximately 3,900 source points can be acquired in a single day assuming a 10-12 hour source effort. When the data from the patch of nodes have been acquired, the node vessels pick up the patch and roll it to the next location. The pickup effort takes approximately 18 hours.

2.2.3.2 Onshore/Intertidal Components

The onshore source effort will be shot holes. These holes are drilled every 50 m (165 ft) along source lines which are orientated perpendicular to the receiver lines and parallel to the coast. To access the onshore drill sites, Apache would use a combination of helicopter portable and tracked vehicle drills. At each source location, Apache will drill to the prescribed hole depth of approximately 10 m (35 ft) and load it with 4 kilograms (kg) (8.8 pounds [lbs]) of explosive (likely Orica OSX Pentolite Explosive). The hole will be capped with a “smart cap” that will make it impossible to detonate the explosive without the proper blaster. At the request of NMFS, Apache conducted a SSV of the onshore shot hole to determine if underwater received sound levels exceeded the NMFS thresholds. The results of the SSV verified received sound levels did not exceed NMFS thresholds (Appendix A), therefore, onshore sources are not discussed further. In the event that the planned charge depth of 10 m (35 ft) is unattainable due to loose sediments collapsing the bore hole, then a SSV will be conducted on the new land based charge depths to determine if they are within NMFS thresholds.

2.2.4 Vessels

The *M/V Peregrine Falcon*, *M/V Arctic Wolf*, *M/V Miss Diane I*, *M/V Mark Steven*, *M/V Maxime*, *M/V Dreamcatcher*, and *M/V Westward Wind*, or similar vessels, will serve as the primary offshore acquisition platforms. The onshore crew will be housed in commercial facilities local near the project site. Offshore staff will be housed on the vessels, which are certified for housing 24-hour crews. Details of the vessels likely to be used are as follows:

M/V Arctic Wolf (Source Vessel)
Size: 41 m X 9 m (135 ft X 30 ft)
Documentation: #687450
Gross Tonnage: 251
Berths: 32

M/V Peregrine Falcon (Source Vessel)
Size: 26 m X 6 m (85 ft X 24 ft)
Documentation: #950245
Call sign: WCZ6285
Gross tonnage: 197
Berths: 10

M/V Westward Wind (Node Charging / Crew Housing Vessel)
Size: 47 m X 10 m (155 ft X 34 ft)
Documentation: #774367
Call sign: WCX9055
Gross tonnage: 131
Berths: 29

M/V Miss Diane I (Node Vessel)
Size: 26 m X 6 m (85 ft X 20 ft)
Documentation: #1210779
Call sign: WAV0779
Gross tonnage: 53
Berths: 6

M/V Mark Steven (Node Vessel)
Size: 26 m X 6.7 m (85 ft X 22 ft)
Documentation: #1238385
Call sign: WAV1238
Gross tonnage: 83
Berths: 16

M/V Maxime (Node Vessel)
Size: 21 m X 4.9 m (70 ft X 16 ft)
Documentation: #1196716
Call sign: WAV6716
Gross tonnage: 48
Berths: 4

M/V Dreamcatcher (Mitigation /chase boat)
Size: 26 m X 7.1 m (85 ft X 23 ft)
Documentation: #963070
Call sign: WBN5411
Gross tonnage: 100
Berths: 32

2.2.5 Fuel Storage

Any fuel storage will be located away from waterways and lakes and positioned in modern containment enclosures. The capacity of the containment will be 110 percent of the total volume of the fuel stored in the bermed enclosures. All storage fuel sites will be equipped with additional absorbent material and spill clean-up tools. Any transfer or bunkering of fuel for offshore activities will either occur dock side or comply with United States Coast Guard (USCG) bunkering at sea regulations.

3.0 Dates, Duration, and Geographical Region of Activities

The dates and duration of such activity and the specific geographical region where it will occur.

3.1 Dates and Durations of Activities

Apache proposes to acquire offshore/transition zone operations for approximately eight to nine months per year, for a five year period beginning in March 2015 through February 29, 2020. Offshore seismic operations will be conducted in the open water periods from March 1st through December 31st. For the proposed acquisition area in Cook Inlet, anticipated windows of operations will be defined by regulatory requirements, subsistence, commercial fishing, the presence of endangered species, as well as environmental conditions such as ice coverage, tides, and weather. Refer to Figure 1 for the area of proposed operations.

During each 24-hour period, seismic support activities may be conducted throughout the entire period; however, in-water airguns will only be active for approximately two to three hours during each slack tide period. There are approximately four slack tide periods in a 24-hour period; therefore, airgun operations will be active during approximately 8-12 hours per day, if conditions allow. Two airgun source vessels will work concurrently on the spread, acquiring source lines approximately 12 km (7.5 mi) in length. Apache anticipates that a crew can acquire approximately 6.2 km^2 (2.4 mi^2) per day, assuming a crew can work 8-12 hours per day.

The vessels will be mobilized out of Homer or Anchorage with resupply runs occurring multiple times per week out of Homer, Anchorage, or Nikiski.

4.0 Type and Abundance of Marine Mammals in Project Area

The species and numbers of marine mammals likely to be found within the activity area.

4.1 Species and Number in the Project Area

Of the 15 marine mammal species with documented occurrences in Cook Inlet, only six species are expected to be observed in the project area: beluga whale (*Delphinapterus leucas*), harbor seal (*Phoca vitulina*), killer whale (*Orcinus orca*), harbor porpoise (*Phocoena phocoena*), gray whale (*Eschrichtius robustus*), and Steller sea lion (*Eumetopiaa jubatus*) (Shelden et al. 2003). Table 1 provides a summary of the abundance and status of the species likely to occur in the project area. While killer whales, gray whales and Steller sea lions have been sighted in upper Cook Inlet, their occurrence is considered uncommon. Cook Inlet beluga whales, harbor porpoises, and harbor seals are the species most likely to be sighted during the seismic program. Recent passive acoustic monitoring research has indicated that harbor porpoises occur more frequently in the project area than expected from previous visual observations (Small 2010). A more detailed description of these five species is provided in Section 5.

There are several species of mysticetes that have been observed infrequently in lower Cook Inlet, including minke whale (*Balaenoptera acutorostrata*), humpback whale (*Megaptera novaeangliae*), and fin whale (*Balaenoptera physalus*). Because of their infrequent occurrence, they are not included in this IHA application. However, monitoring and mitigation techniques for these species and other observed marine mammals would be performed to avoid Level A and Level B takes.

Table 1. Marine Mammal Species in Cook Inlet

Species	Abundance	Comments
Beluga whale (*Delphinapterus leucas*)	283 [1]	Occurs in the project area. Listed as Depleted under the MMPA, endangered under ESA, critical habitat designated in project area.
Harbor seal *(Phoca vitulina richardsi)*	22,900 [2]	Occurs in the project area. No special status or ESA listing.
Killer whale *(Orcinus orca)*	1,123 Resident 552 Transient [3]	Occurs rarely in the project area. No special status or ESA listing.
Harbor porpoise *(Phocoena phocoena)*	25,987 [4]	Occurs in the project area. No special status or ESA listing.
Steller sea lion (*Eumetopias jubatus*)	45,916 [5]	Occurs infrequently in the project area. Listed as Depleted under the MMPA, endangered under ESA.
Gray whale (*Eschrichtius robustus)*	18,017 [6]	Occurs infrequently in the project area. No special status or ESA listing.

Notes: MMPA = Marine Mammal Protection Act, ESA = Endangered Species Act

[1] Abundance estimate for the Cook Inlet stock (Allen and Angliss 2013)

[2] Abundance estimate for the Cook Inlet/Shelikof stock (Allen and Angliss 2013)

[3] Resident estimate from Alaska resident stock; transient estimate from Gulf of Alaska, Aleutian Islands, and Bering Sea transient stock (Allen and Angliss 2013)

[4] Abundance estimate for the Gulf of Alaska stock (Allen and Angliss 2013)

[5] Abundance estimate for the western stock (Allen and Angliss 2013)

[6] Abundance estimate for the Eastern North Pacific stock (Wade and Angliss 1997, Carretta et al. 2014)

5.0 Description of Marine Mammals in Project Area

A description of the status, distribution, and seasonal distribution of the affected species or stocks of marine mammals likely to be affected by such activities.

5.1 Harbor Seal

Harbor seals range from Baja California north along the west coasts of Washington, Oregon, California, British Columbia, and Southeast Alaska; west through the Gulf of Alaska, Prince William Sound, and the Aleutian Islands; and north in the Bering Sea to Cape Newenham and the Pribilof Islands. In 2010, NMFS and the Alaska Harbor Seal Commission decided to separate the three previous harbor seal stocks (Gulf of Alaska, Southeast Alaska, and Bering Sea) into 12 new stocks. The Cook Inlet/Shelikof stock is the stock most likely to occur in Apache's project area and is estimated to have 22,900 individuals (Allen and Angliss 2013). Harbor seals are taken incidentally during commercial fishery operations at an estimated annual mortality of 24 individuals (Allen and Angliss 2010).

Harbor seals inhabit the coastal and estuarine waters of Cook Inlet. Harbor seals have historically been more abundant in lower Cook Inlet than upper Cook Inlet (Rugh et al. 2005 a, b); a tagging study indicated that breeding and molting likely peak in Cook Inlet in June and August (respectively), with most of these behaviors occurring in the lower portion of Cook Inlet south of the forelands (Boveng et al. 2007). Apache aerial observers recorded approximately 900 seals north of the forelands in 2012 (Lomac MacNair et al. 2013). Moreover, preliminary reports from Apache's 2014 vessel, aerial, and land observations suggest harbor seals may be more abundant north of the forelands than previously understood. Continued marine mammal observations throughout Apache's five year program will help to better understand harbor seal distributions in upper and lower Cook Inlet.

Important harbor seal life functions such as breeding and molting may occur within portions of Apache's proposed survey in June and August, but the co-occurrence is expected to be minimal (most seals observed from vessel and land based stations were single individuals and likely were not breeding or molting). From November through January, harbor seals leave Cook Inlet to forage in Shelikof Strait, so Apache's proposed operations would not interfere with foraging behavior (Boveng et al. 2007).

Harbor seals haul out on rocks, reefs, beaches, and drifting glacial ice, and feed on capelin, eulachon, cod, pollock, flatfish, shrimp, octopus, and squid in marine, estuarine, and occasionally fresh waters. Harbor seals movements are associated with tides, weather, season, food availability, and reproduction.

The major haulout sites for harbor seals are located in lower Cook Inlet. The presence of harbor seals in upper Cook Inlet is seasonal. Harbor seals are commonly observed along the Susitna River and other tributaries within upper Cook Inlet during eulachon and salmon migrations (NMFS 2003). During aerial surveys of upper Cook Inlet in 2001, 2002, and 2003, harbor seals were observed at the Chickaloon, Little Susitna, Susitna, Ivan, McArthur, and Beluga Rivers (Rugh et al. 2005a). The closest traditional haulout site to the project area is located on Kalgin Island, which is about 22 km (14 mi) south of the McArthur River.

Harbor seals respond to underwater sounds from approximately 1 to 80 kHz with the functional high frequency limit around 60 kHz and peak sensitivity at about 32 kHz (Kastak and Schusterman 1995). Hearing ability in the air is greatly reduced (by 25 to 30 dB); harbor seals respond to sounds from 1 to 22.5 kHz, with a peak sensitivity of 12 kHz (Kastak and Schusterman 1995). Figure 8 is an in-air audiogram and Figure 9 is an in-water audiogram for the harbor seal (taken from Nedwell et al. 2004). An audiogram shows the lowest level of sounds that the animal can hear (hearing threshold) at different frequencies (pitch). The y-axis of the audiogram is sound levels expressed in dB (either in-air or in-water) and the x-axis is the frequency of the sound expressed in kHz.

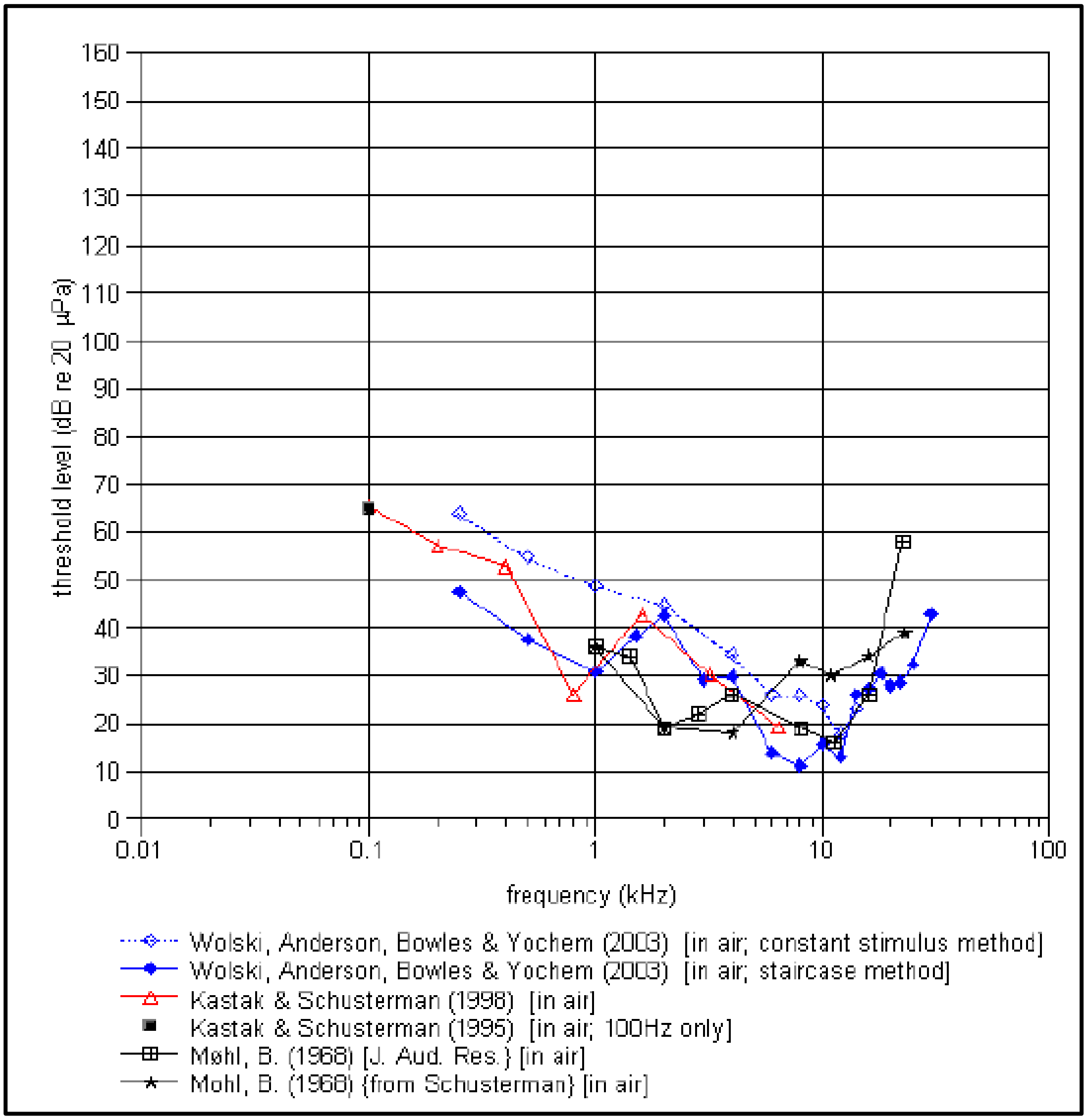


Figure 8. Harbor Seal In-air Audiogram (taken from Nedwell et al. 2004)

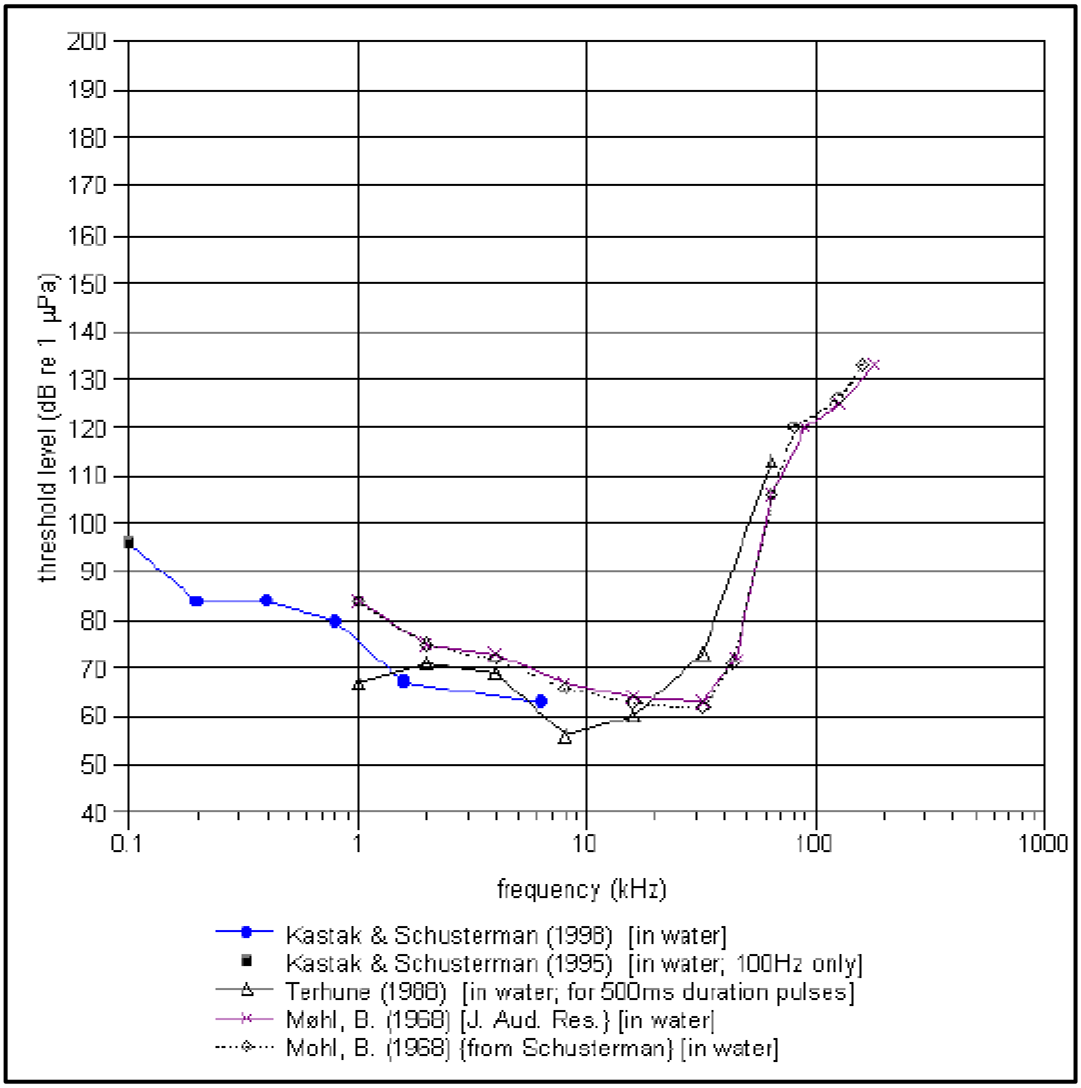


Figure 9. Harbor Seal In-water Audiogram (taken from Nedwell et al. 2004)

5.2 Killer Whale

The population of the North Pacific stock of killer whales contains an estimated 1,123 animals in the resident group and 552 animals in the transient group (Allen and Angliss 2013). Numbers of killer whales in Cook Inlet are small compared to the overall population and most are recorded in the lower Cook Inlet. Killer whales are rare in upper Cook Inlet, where transient killer whales are known to feed on beluga whales, and resident killer whales are known to feed on anadromous fish (Shelden et al. 2003). The availability of these prey species largely determines the likeliest times for killer whales to be in the area. Twenty-three sightings of killer whales were reported in the lower Cook Inlet between 1993 and 2004 in aerial surveys by Rugh et al. (2005a). Surveys over 20 years by Shelden et al. (2003) reported 11 sightings in upper Cook Inlet between Turnagain Arm, Susitna Flats, and Knik Arm. No killer whales were spotted during recent surveys by Funk et al. (2005), Ireland et al. (2005), Brueggeman et al. (2007a, 2007b, 2008), or Prevel Ramos et al. (2006, 2008). Eleven killer whale strandings have been reported in Turnagain Arm, six in May 1991, and five in August 1993. Very few killer whales, if any, are expected to approach or be in the vicinity of the project area.

The hearing of killer whales is well developed. Szymanski et al. (1999) found that they responded to tones between 1 and 120 kHz, with the most sensitive range between 18 and 42 kHz. Their greatest sensitivity was at 20 kHz, which is lower than many other odontocetes, but it matches peak spectral energy reported for killer whale echolocation clicks. Figure 10 is an audiogram for the killer whale (taken from Nedwell et al. 2004).

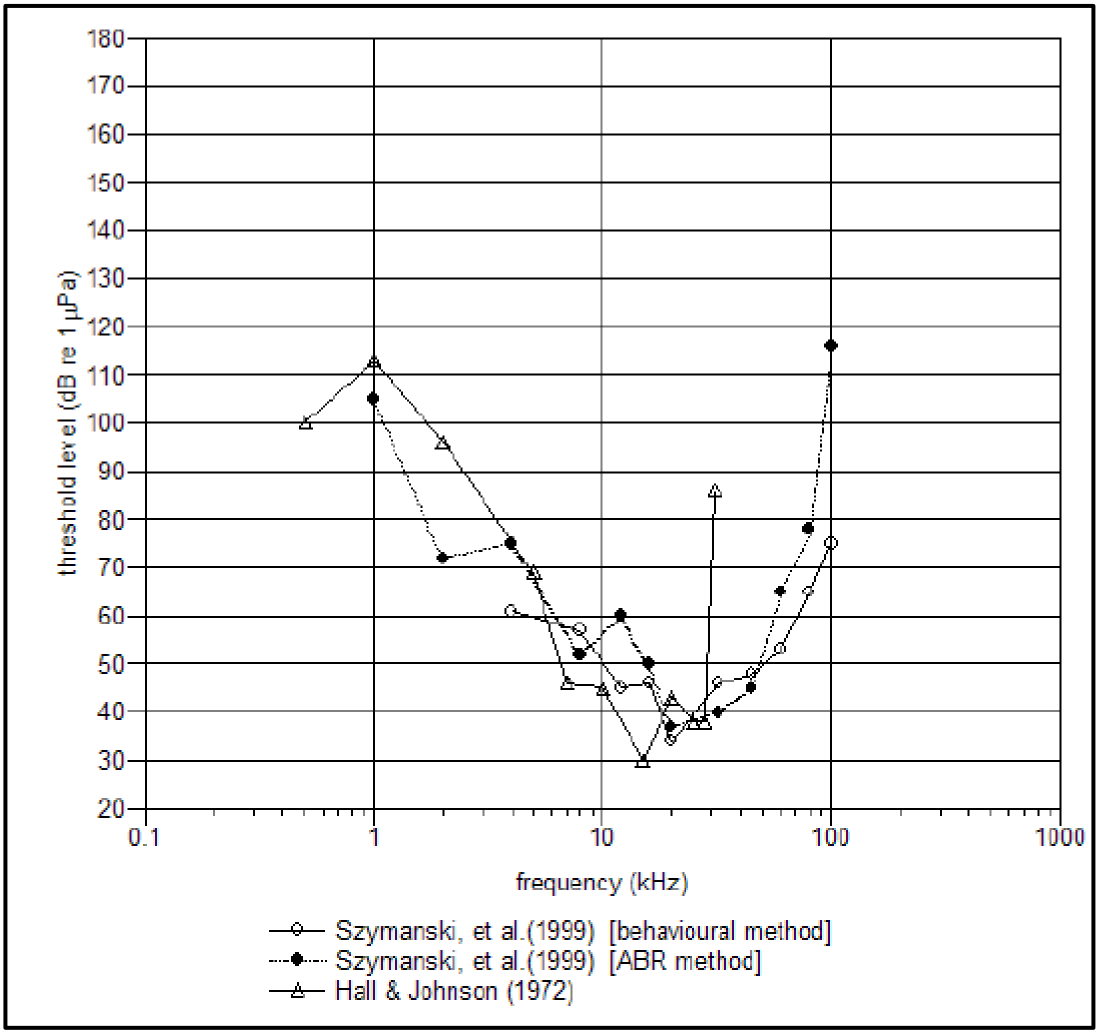


Figure 10. Killer Whale In-water Audiogram (taken from Nedwell et al. 2004)

5.3 Harbor Porpoise

Harbor porpoise stocks in Alaska are divided into three stocks: the Bering Sea stock, the Southeast Alaska stock, and the Gulf of Alaska stock. The Gulf of Alaska stock is currently estimated at 25,987 individuals (Allen and Angliss 2013). A recent estimated density of animals in Cook Inlet is 7.2 per 1,000 km^2 (386 mi^2) (Dahlheim et al. 2000) indicating that only a small number use Cook Inlet. Harbor porpoise have been reported in lower Cook Inlet from Cape Douglas to the West Foreland, Kachemak Bay, and offshore (Rugh et al. 2005a). Small numbers of harbor porpoises have been consistently reported in the upper Cook Inlet between April and October, except for a recent survey that recorded higher numbers than typical (Prevel Ramos et al. 2008). Reports from 2006 and 2007 show the highest monthly counts between Granite Point and the Susitna River include 17 harbor porpoises reported for spring through fall 2006 by Prevel Ramos et al. (2008), 14 for spring of 2007 by Brueggeman et al. (2007a), 12 for fall of 2007 by Brueggeman et al. (2008), and 129 for spring through fall in 2007 by Prevel Ramos et al. (2008). The reason for the recent spike in numbers (129) of harbor porpoises in the upper Cook Inlet is unclear and quite disparate with results of past surveys, suggesting it may be an anomaly. The spike occurred in July, which was followed by sightings of 79 harbor porpoise in August, 78 in September, and 59 in October in 2007. The number of porpoises counted more than once was unknown indicating that the actual numbers are likely smaller than reported. In 2012, Apache marine mammal observers recorded 137 sightings of 190 estimated individuals; a similar count to the 2007 spike previously observed. Although only 0.7 percent of the Gulf of Alaska population, the increase of sightings in the upper Cook Inlet may reflect movement of harbor porpoise distribution than previously known.

Recent passive acoustic research in Cook Inlet by ADF&G and National Marine Mammal Laboratory (NMML) have indicated that harbor porpoises occur more frequently than expected, particularly in the West Foreland area in the spring (NMML 2011, personal communication), although overall numbers are still unknown at this time.

The harbor porpoise has the highest upper-frequency limit of all odontocetes investigated. Kastelein et al. (2002) found that the range of best hearing was from 16 to 140 kHz, with a reduced sensitivity around 64 kHz. Maximum sensitivity (about 33 dB re 1 µPa) occurred between 100 and 140 kHz. This maximum sensitivity range corresponds with the peak frequency of echolocation pulses produced by harbor porpoises (120-130 kHz). Figure 11 is an audiogram for the harbor porpoise (taken from Nedwell et al. 2004).

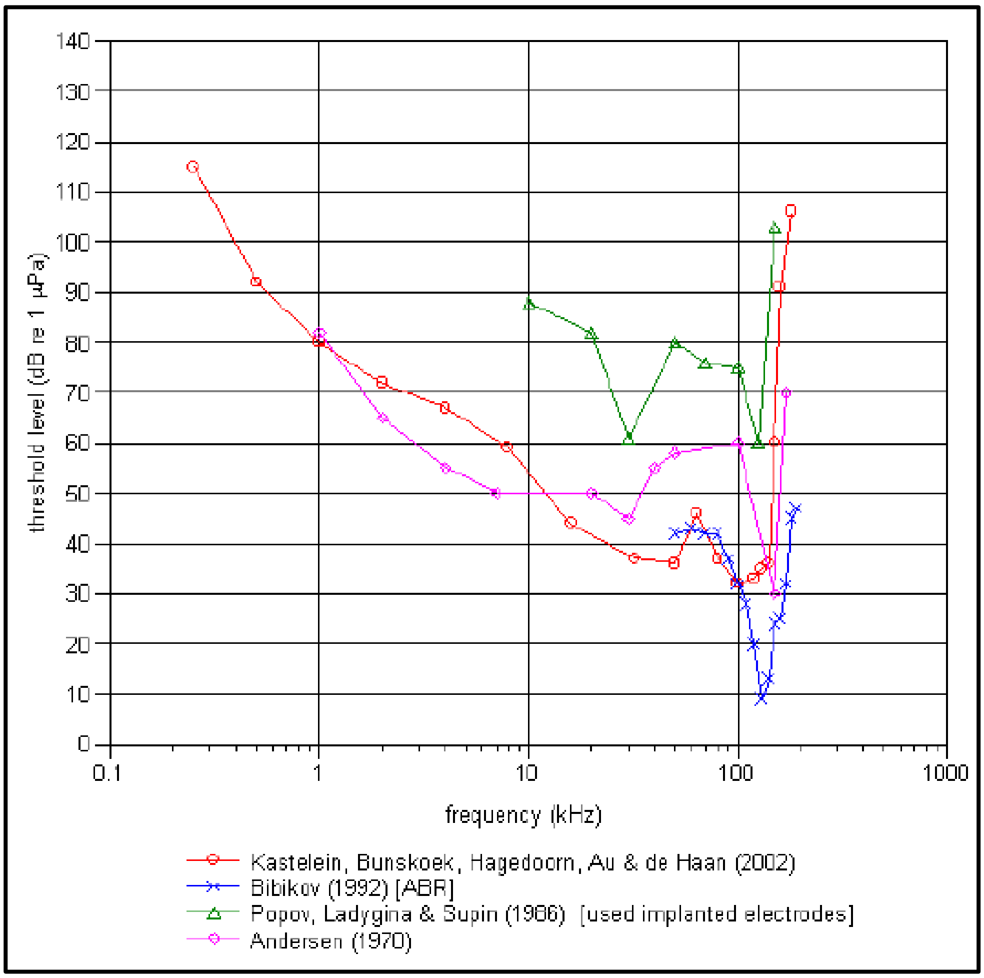


Figure 11. Harbor Porpoise In-water Audiogram (taken from Nedwell et al. 2004)

5.4 Beluga Whale

Beluga whales appear seasonally throughout much of Alaska, except in the Southeast region and the Aleutian Islands. Five stocks are recognized in Alaska: Beaufort Sea stock, eastern Chukchi Sea stock, eastern Bering Sea stock, Bristol Bay stock, and Cook Inlet stock (Allen and Angliss 2010). The Cook Inlet stock is the most isolated of the five stocks, as it is separated from the others by the Alaska Peninsula and resides year round in Cook Inlet (Laidre et al. 2000). Only the Cook Inlet stock inhabits the project area.

5.4.1 Population

Cook Inlet beluga whales may have numbered fewer than several thousand animals but there were no systematic population estimates prior to 1994. Although ADF&G conducted a survey in August 1979, it did not include all of upper Cook Inlet, the area where almost all beluga whales are currently found during summer. However, it is the most complete survey of Cook Inlet prior to 1994 and incorporated a correction factor for beluga whales missed during the survey. Therefore, the ADF&G summary (Calkins 1989) provides the best available estimate for the historical beluga whale abundance in Cook Inlet. For management purposes, NMFS has adopted 1,300 beluga whales as the numerical value for the carrying capacity to be used in Cook Inlet (65 FR 34590).

NMFS began comprehensive, systematic aerial surveys on beluga whales in Cook Inlet in 1994. Unlike previous efforts, these surveys included the upper, middle, and lower inlet. These surveys documented a decline in abundance of nearly 50 percent between 1994 and 1998, from an estimate of 653 to 347 whales (Rugh et al. 2000). In response to this decline, NMFS initiated a status review on the Cook Inlet beluga whale stock pursuant to the Marine Mammal Protection Act (MMPA) and the ESA in 1998 (63 FR 64228). The annual abundance surveys conducted each June since 1999 provide the following abundance estimates: 367 beluga whales in 1999, 435 beluga whales in 2000, 386 beluga whales in 2001, 313 beluga whales in 2002, 357 beluga whales in 2003, 366 beluga whales in 2004, 278 beluga whales in 2005, 305 beluga whales in 2006, 375 beluga whales in 2007; 321 beluga whales in 2009; 340 beluga whales in 2010; 284 belugas in 2011; and 312 belugas in 2012 (Hobbs et al. 2000; Rugh et al. 2003, 2004a, 2004b, 2005a, 2005b, 2005c, 2006, 2007; Hobbs et al. 2011; Shelden et al. 2012).

These results show the population is not growing and is exhibiting a decline of 1.1 percent per year (Hobbs et al. 2011). The Cook Inlet beluga whale population has been designated as depleted under the MMPA (65 FR 34590). This designation is because the current minimum population estimate (283 – Allen and Angliss 2013) places it at about 36 percent of the Optimum Sustainable Population (OSP) of 780 whales (60 percent of the estimated carrying capacity of 1,300 whales). The estimate has remained below half of the OSP, which is the threshold NMFS is required to use to designate the population as depleted under the MMPA (Angliss and Outlaw 2008).

In 1999, NMFS received petitions to list the Cook Inlet beluga whale stock as an endangered species under the ESA (64 FR 17347). However, NMFS determined that the population decline was due to over harvest by Alaska Native subsistence hunters and, because the Native harvest was regulated in 1999, listing this stock under the ESA was not warranted at the time (65 FR 38778). This decision was upheld in court. In 2006, NMFS announced initiation of another Cook Inlet beluga whale status review under the ESA (71 FR 14836) and received another petition to list the Cook Inlet beluga whale under the ESA (71 FR 44614). NMFS issued a decision on the status review on April 20, 2007 concluding that the Cook Inlet beluga whale is a distinct population segment that is in danger of extinction throughout its range; NMFS issued a proposed rule to list the Cook Inlet beluga whale as an endangered species (72 FR 19821). Public hearings were conducted in July 2007, and the comment period extended to August 3, 2007. On April 22, 2008, NMFS announced that it would delay the decision on the proposed rule until after it had assessed the population status in the summer of 2008, moving the deadline for the decision to October 20, 2008 (73 FR 21578). On October 17, 2008, NMFS announced that the population is listed as endangered under ESA (73 FR 62919). On April 11, 2011, NMFS announced the two areas of critical habitat (76 FR 20180) comprising 7,800 km^2 (3,013 mi^2) of marine habitat (Figure 12). NMFS also released the Final Conservation Plan (NMFS 2008b).

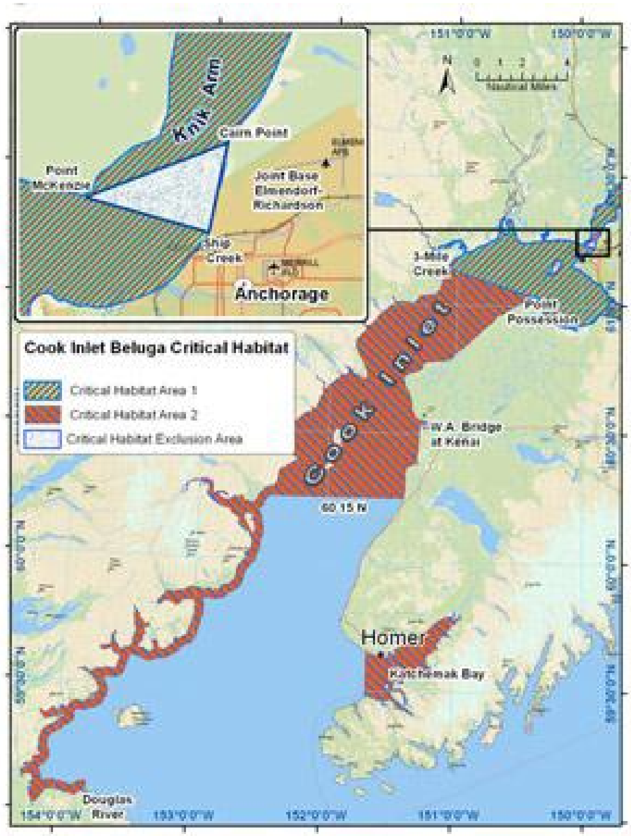


Figure 12. Final Critical Habitat of Cook Inlet Beluga Whales (76 FR 20180, April 11, 2011)

5.4.2 Hearing Abilities

In terms of hearing abilities, beluga whales are one of the most studied odontocetes because they are a common marine mammal in public aquariums around the world. Although they are known to hear a wide range of frequencies, their greatest sensitivity is around 10 to 100 kHz (Richardson et al. 1995), well above sounds produced by most industrial activities (<100 hertz [Hz] or 0.1 kHz) recorded in Cook Inlet. Average hearing thresholds for captive beluga whales have been measured at 65 and 121 dB re 1 µPa at frequencies of 8 kHz and 125 Hz, respectively (Awbrey et al. 1988). Masked hearing thresholds were measured at approximately 120 dB re 1 µPa for a captive beluga whale at three frequencies between 1.2 and 2.4 kHz (Finneran et al. 2002a; Finneran et al. 2002b). Beluga whales do have some limited hearing ability down to ~35 Hz, where their hearing threshold is about 140 dB re 1 µPa (Richardson et al. 1995). Thresholds for pulsed sounds will be higher, depending on the specific durations and other characteristics of the pulses (Johnson 1991). An audiogram for beluga whales from Nedwell et al. (2004) is provided in Figure 13.

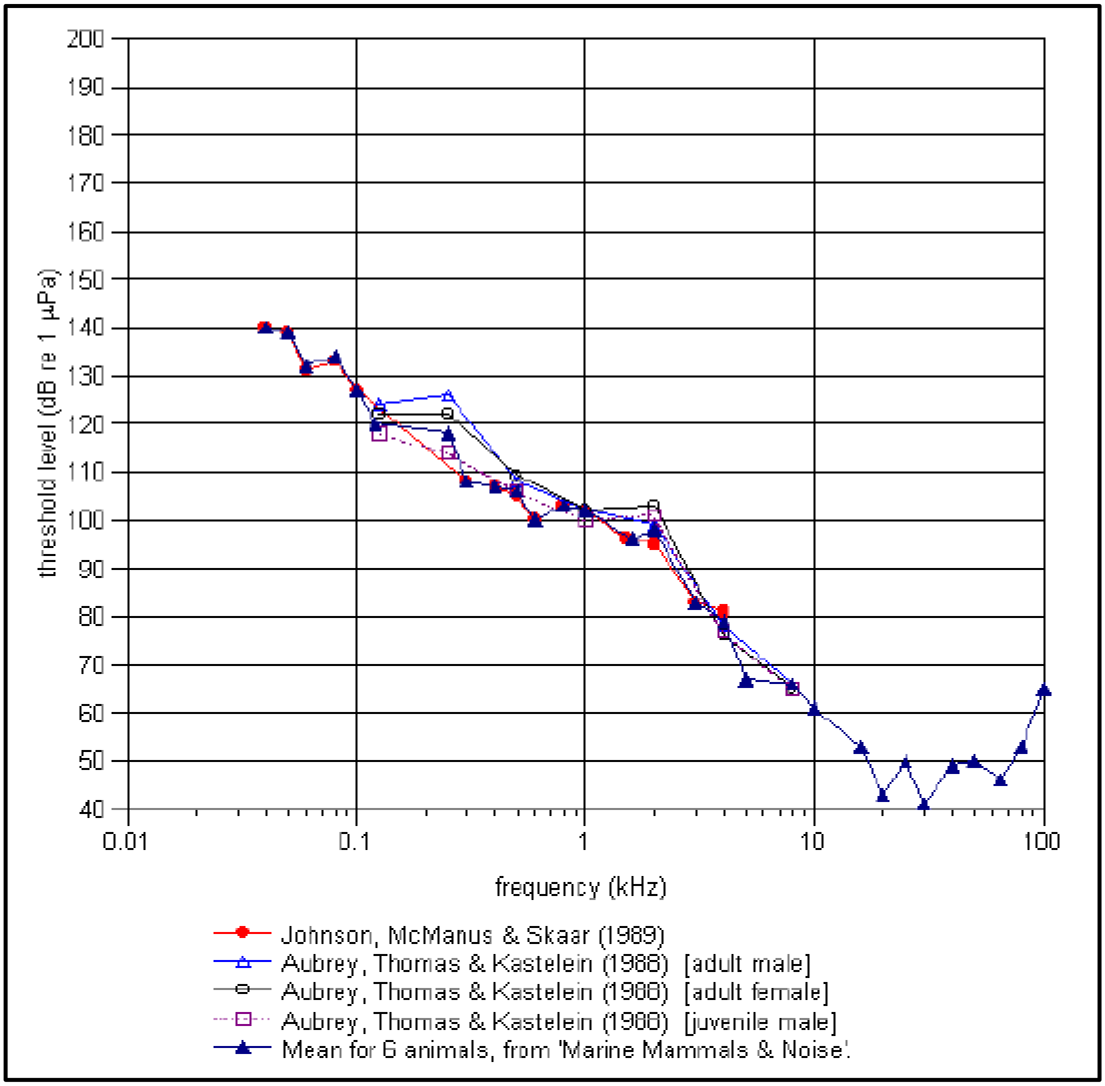


Figure 13. Beluga Whale In-water Audiogram (taken from Nedwell et al. 2004)

5.4.3 Distribution

The Cook Inlet beluga whale has been historically distributed throughout Cook Inlet, with occasional sightings in the Gulf of Alaska (Huntington 2000; Laidre et al. 2000; Rugh et al. 2000). In recent years the range of the Cook Inlet beluga whale has contracted to the upper reaches of Cook Inlet (Rugh et al. 2010).

The following discussion of the distribution of beluga whales in upper Cook Inlet is based upon NMML data including NMFS aerial surveys (Figure 14); NMFS data from satellite-tagged belugas and opportunistic sightings (NMML 2004); baseline studies of beluga whale occurrence in Knik Arm conducted for Knik Arm Bridge and Toll Authority (KABATA) (Funk et al. 2005); Marine Mammal Monitoring at the Port of Anchorage (POA) (Cornick and Kendall 2008a, 2008b; Cornick et al. 2010; Markowitz et al. 2007; Prevel Ramos et al. 2006; Širović and Kendall 2009); baseline studies of beluga whale occurrence in Turnagain Arm conducted in preparation for Seward Highway improvements (Markowitz et al. 2007); marine mammal surveys conducted at Ladd Landing to assess a coal shipping project (Prevel Ramos et al. 2008); marine mammal surveys off Granite Point, the Beluga River, and further down the inlet at North Ninilchik (Brueggeman et al. 2007a, 2007b, 2008); passive acoustic monitoring of beluga whales in Cook Inlet (Small 2010); and Apache 2D Seismic Test Program (Apache monthly reports).

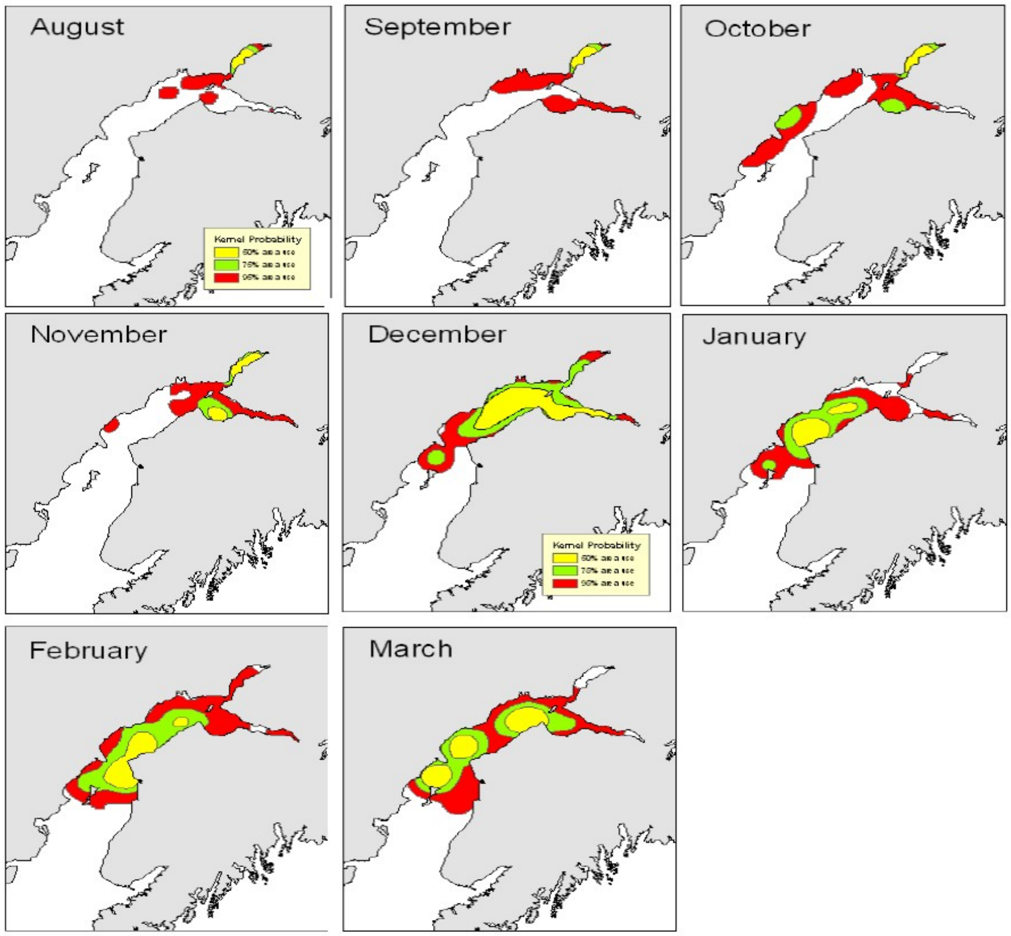


Figure 14. Predicted beluga distribution by month.

The monthly beluga whale probabilities presented in Figure 14 are based on the known locations of 14 satellite tagged belugas (predictions derived via kernel probability estimates; Hobbs et al. 2005). The large increase in total area use and offshore locations beginning in December and continuing through March. The red area (95 percent probability) encompasses the green (75 percent) and yellow (50 percent) regions. From NMFS 2008b.

5.4.3.1 NMFS Aerial Surveys

Since 1993, NMFS has conducted annual aerial surveys in June or July to document the distribution and abundance of beluga whales in Cook Inlet. In addition, to help establish beluga whale distribution in Cook Inlet throughout the year, aerial surveys were conducted every one to two months between June 2001 and June 2002 (Rugh et al. 2004a). These annual aerial surveys for beluga whales in Cook Inlet have provided systematic coverage of 13 to 33 percent of the entire inlet each June or July since 1994 including a 3 km (1.9 mi) wide strip along the shore and approximately 1,000 km (621 mi) of offshore transects (Rugh et al. 2000, 2005a, 2005b, 2006, 2007). Surveys designed to coincide with known seasonal feeding aggregations (Table 1.3 in Rugh et al. 2000) were generally conducted on two to four days per year in June or July at or near low tide in order to reduce the search area (Rugh et al. 2000). However, from June 2001 to June 2002, surveys were conducted during most months in an effort to assess seasonal variability in beluga whale distribution in Cook Inlet (Rugh et al. 2005a).

The collective survey results show that beluga whales have been consistently found near or in river mouths along the northern shores of upper Cook Inlet (i.e., north of East and West Foreland). In particular, beluga whale groups are seen in the Susitna River Delta, Knik Arm, and along the shores of Chickaloon Bay. Small groups had also been recorded farther south in Kachemak Bay, Redoubt Bay (Big River), and Trading Bay (McArthur River) prior to 1996, but very rarely thereafter. Since the mid-1990s, most (96 to 100 percent) beluga whales in upper Cook Inlet have been concentrated in shallow areas near river mouths, no longer occurring in the central or southern portions of Cook Inlet (Hobbs et al. 2008). Based on these aerial surveys, the concentration of beluga whales in the northernmost portion of Cook Inlet appears to be fairly consistent from June to October (Rugh et al. 2000, 2004a, 2005a, 2006, 2007; Shelden et al. 2008, 2009, 2010; Shelden et al. 2012).

5.4.3.2 NMFS Satellite Tag Data

In 1999, one beluga whale was tagged with a satellite transmitter, and its movements were recorded from June through September of that year. Since 1999, 18 beluga whales in upper Cook Inlet have been captured and fitted with satellite tags to provide information on their movements during late summer, fall, winter, and spring. Hobbs et al. (2005) described: 1) the recorded movements of two beluga whales (tagged in 2000) from September 2000 through January 2001; 2) the recorded movements of seven beluga whales (tagged in 2001) from August 2001 through March 2002; and 3) the recorded movements of eight beluga whales (tagged in 2002) from August 2002 through May 2003.

The concentration of beluga whales in upper Cook Inlet appears to be fairly consistent from June to October based on aerial surveys (Rugh et al. 2000, 2004a, 2005a). Studies for KABATA in 2004 and 2005 confirmed the use of Knik Arm by beluga whales from July to October (Funk et al. 2005). Data from tagged whales (14 tags between July and March 2000 through 2003) show beluga whales use upper Cook Inlet intensively between summer and late autumn (Hobbs et al. 2005). As late as October, beluga whales tagged with satellite transmitters continued to use Knik Arm and Turnagain Arm and Chickaloon Bay, but some ranged into lower Cook Inlet south to Chinitna Bay, Tuxedni Bay, and Trading Bay (McArthur River) in the fall (Hobbs et al. 2005). In November, beluga whales moved between Knik Arm, Turnagain Arm, and Chickaloon Bay, similar to patterns observed in September (Hobbs et al. 2005). By December, beluga whales were distributed throughout the upper to mid-inlet. From January into March, they moved as far south as Kalgin Island and slightly beyond in central offshore waters. Beluga whales also made occasional excursions into Knik Arm and Turnagain Arm in February and March in spite of ice cover greater than 90 percent (Hobbs et al. 2005). While they moved widely around Cook Inlet, there was no indication that tagged whales (Hobbs et al. 2005) had a seasonal migration in and out of Cook Inlet.

5.4.3.3 Opportunistic Sightings

Opportunistic sightings of beluga whales in Cook Inlet have been reported to the NMFS since 1977. Beluga whale sighting reports are maintained in a database by NMML. Their high visibility and distinctive nature make them well-suited for opportunistic sightings along public access areas (e.g., the Seward Highway along Turnagain Arm and the public boat ramp at Ship Creek). Opportunistic sighting reports come from a variety of sources including: NMFS personnel conducting research in Cook Inlet, ADF&G, commercial fishermen, pilots, and the general public. Location data range from precise locations (e.g., GPS-determined latitude and longitude) to approximate distances from major landmarks. In addition to location data, most reports include date, time, approximate number of whales, and notable whale behavior (Rugh et al. 2000, 2004a, 2005a). Since opportunistic data are collected any time, and often multiple times a week, these data often provide an approximation of beluga whale locations and movements in those areas frequented by natural resource agency personnel, fishermen, and others.

Depending upon the season, beluga whales can occur in both offshore and coastal waters. Although they remain in the general Cook Inlet area during the winter, they disperse throughout the upper and mid-inlet areas. Data from NMFS aerial surveys, opportunistic sighting reports, and satellite-tagged beluga whales confirm they are more widely dispersed throughout Cook Inlet during the winter months (November - April), with animals found between Kalgin Island and Point Possession. Based upon monthly surveys (e.g., Rugh et al. 2000), opportunistic sightings, and satellite-tag data, there are generally fewer observations of these whales in the Anchorage and Knik Arm area from November through April (NMML 2004; Rugh et al. 2004a).

During the spring and summer, beluga whales are generally concentrated near the warmer waters of river mouths where prey availability is high and predator occurrence is low (Moore et al. 2000). Most beluga whale calving in Cook Inlet occurs from mid-May to mid-July in the vicinity of the river mouths, although Native hunters have described calving as early as April and as late as August (Huntington 2000).

Beluga whale concentrations in upper Cook Inlet during April and May correspond with eulachon migrations to rivers and streams in the northern portion of upper Cook Inlet (NMFS 2003; Angliss and Outlaw 2005). Data from NMFS aerial surveys, opportunistic sightings, and satellite-tagged beluga whales confirm that they are concentrated along the rivers and nearshore areas of upper Cook Inlet (Susitna River Delta, Knik Arm, and Turnagain Arm) from May through October (NMML 2004; Rugh et al. 2004a). Beluga whales are commonly seen from early July to early October at the mouth of Ship Creek where they feed on salmon and other fish, and also in the vicinity of the Port (e.g., alongside docked ships and within 91 m [300 ft] of the docks) (Blackwell and Greene 2002; NMML 2004). Beluga whales have also been observed feeding immediately offshore of the tidelands north of the Port and south of Cairn Point (NMFS 2004).

5.4.3.4 KABATA 2004 - 2005 Baseline Study

To assist in the evaluation of the potential impact of a proposed bridge crossing of Knik Arm north of Cairn Point, KABATA initiated a study to collect baseline environmental data on beluga whale activity and the ecology of Knik Arm. Boat and land-based observations were conducted in Knik Arm from July 2004 through July 2005. Land-based observations were conducted from nine stations along the shore of Knik Arm. The three primary stations were located at Cairn Point, Point Woronzof, and Birchwood. The majority of the beluga whales were observed north of Cairn Point. Temporal use of Knik Arm by beluga whales was related to tide height. During the study period, most beluga whales using Knik Arm stayed in the upper portion of Knik Arm north of Cairn Point. Approximately 90 percent of observations occurred from August through November, and only during this time were whales consistently sighted in Knik Arm. The relatively low number of sightings in Knik Arm throughout the rest of the year suggested the whales were using other portions of Cook Inlet. In addition, relatively few beluga whales were sighted in the spring and early to mid-summer months. Beluga whales predominantly frequented Eagle Bay (mouth of Eagle River), Eklutna, and the stretch of coastline in between, particularly when they were present in greater numbers (Funk et al. 2005).

5.4.3.5 Marine Mammal Monitoring at the Port of Anchorage

To meet the permit requirements for the POA Marine Terminal Redevelopment (MTR) Project, land-based visual surveys have been conducted in Knik Arm near Cairn Point north of the MTR Project since 2005 (Prevel Ramos et al. 2006; Markowitz et al. 2007; Cornick and Kendall 2008a, 2008b; Cornick et al. 2010). The results from these studies are consistent with the results from the NMFS's aerial surveys and KABATA's baseline studies, indicating beluga whales are commonly observed in Knik Arm in late summer through the fall (August through mid-November). The results also indicate that belugas are most often observed along the eastern shoreline adjacent to the MTR Project.

In addition to land-based surveys, the POA was required to conduct a passive acoustic marine mammal monitoring program adjacent to the MTR Project. The passive acoustic monitoring program was conducted for 20 days in August and September, 2009 (Širović and Kendall 2009). Four moored sonobuoys were deployed in a rhomboid formation at the beginning of each day of monitoring and data were collected in real-time at a land-based observation station. Acoustic monitoring continued for approximately 8-10 hours per day. Beluga whales were detected 14 out of the 20 days of monitoring (six days in August and eight days in September), most commonly on the sonobuoys located near the center of Knik Arm, adjacent to the deep channel (Širović and Kendall 2009).

5.4.3.6 Seward Highway Study along Turnagain Arm

Markowitz et al. (2007) documented habitat use and behavior of beluga whales along the Seward Highway in Turnagain Arm from May through November 2006. This study was focused around the high tides when whales regularly traverse the near-shore channels to the mouths of rivers and streams, where they feed on fish. Most of the observations of whales occurred between the end of August and the end of October. No beluga whales were sighted in the study area in May, June, or July. The age composition of all whales observed was 58 percent adults, 17 percent subadults, 8 percent calves, and 17 percent unknown. Most beluga whale observations were in the upper Turnagain Arm, east of Bird Creek. The observation station closest to the Port was at Potter Creek but few beluga whales were sighted in the lower Turnagain Arm section of the project area. About 80 percent of all beluga whale sightings were within 1,100 m (3,600 ft) of shore. About a third of all sightings in September were less than 50 m (164 ft) from shore while two-thirds of all sightings in October were within 50 m (164 ft) of shore. Most beluga whale movements were with the tide: eastward into the upper Turnagain Arm on the rising tide and westward out of Turnagain Arm on the falling tide. The few observations of beluga whales in the lower Turnagain Arm were close to the mid-tide, indicating that beluga whales may use these areas closer to the low tide rather than the high tide pattern observed in the upper Turnagain Arm.

5.4.3.7 Marine Mammal Surveys at Ladd Landing

Prevel Ramos et al. (2008) conducted surveys near Ladd Landing on the north side of upper Cook Inlet between Tyonek and the Beluga River from April through October in 2006 and July through October 2007. The results from 2006 indicated that July through October had the least amount of beluga whale activity in the project area. Relatively few beluga whales were observed during the 2007 surveys near Ladd Landing, with three groups of one or two whales observed in July, two groups of three whales in September, and two groups averaging seven whales in October. Two groups of 20 whales were observed near the Susitna Flats in August. Some of these whales may have been recorded more than once. Most of the whales sighted were close to shore. Of the whales seen in 2006 and 2007, 60 to 75 percent were white, 16 to 18 percent were gray, and the color of 10 to 22 percent was unknown.

5.4.3.8 Marine Mammal Surveys at Granite Point, Beluga River, and North Ninilchik

Brueggeman et al. (2007a, 2007b, 2008) conducted vessel and aerial surveys in 2007 near the Beluga River between April 1 and May 15, Granite Point between September 29 and October 21, and North Ninilchik between October 25 and November 7. They recorded 148 to 162 belugas near the Beluga River with most observed during early May, 35 belugas near Granite Point with most observed in early to mid-October, and no belugas recorded off North Ninilchik. Most of the whales were observed near the shore. In addition, the movements indicated they were transiting to the head of the upper inlet. Small percentages of calves and yearlings were recorded with adults during the spring and early fall surveys. No belugas were observed at North Ninilchik which is considered marginal habitat because of a lack of habitat structure (bays, inlets, etc.) combined with easy public access, typical of the eastern shore of the inlet.

5.4.3.9 Passive Acoustic Monitoring of Cook Inlet Beluga Whales (ADF&G)

An ongoing study by Small (2010) deployed acoustic recording devices throughout Cook Inlet in May 2009. The acoustic recording devices were deployed in Knik Arm (three in Eagle Bay and one near Cairn Point), near Fire Island, near Beluga and Kenai Rivers, in Trading Bay, Tuxedni Bay and Kachemak Bay. Results from June - October 2009 (summer, fall) identify beluga whales at the following locations: Knik Arm, Fire Island, Beluga and Kenai Rivers and Trading Bay. Results from October 2009 - May 2010 (fall, winter, spring) identify beluga whales in the same areas. These results indicate beluga whales are generally distributed throughout the middle to upper Cook Inlet.

5.4.3.10 2011 Apache 2D Seismic Test Program

Apache conducted a two-dimensional (2D) seismic test program along the west coast of Redoubt Bay, lower Cook Inlet from March 17 - April 2, 2011. The objective of the Cook Inlet 2D Seismic Test Program was to evaluate new nodal technology seismic recording equipment for operations in this environment and test seismic acquisition parameters in order to finalize the design for a planned seismic program in Cook Inlet. The test had an onshore, transition zone and offshore component that included the use of input/output sleeve airguns in four different configurations of arrays (880, 1,200, 1,760, and 2,400 in^3). The seismic operation was active 24 hours per day, although the in-water airguns were only active during the daylight slack tide periods. During the Cook Inlet 2D Seismic Test Program, beluga whales were sighted on three different occasions: once from the vessels and twice during aerial observations. A total of 33 beluga whales were sighted during the survey. On March 27, a group of seven beluga whales were observed traveling near the West Foreland and a group of 25 belugas were observed milling near Drift River. On March 28, a lone individual was observed traveling near Drift River.

5.4.3.11 2011 and 2012 Apache Sound Source Verification Surveys

Apache also conducted a sound source verification survey (SSV) on September 17-18, 2011 to characterize underwater received sound levels resulting from land-based explosives (Appendix A). The survey took place in Trading Bay near the town of Shirleyville and extended 6.4 km (4 mi) along the northwest side of Nikolai Creek. There were no sightings of beluga whales before, during or after the survey.

Apache conducted an SSV on May 7-8, 2012 to verify underwater received sound levels from in-water airguns (Appendix B) near the town of Shirleyville in Trading Bay. On May 7, two beluga whales were observed milling, a group of three adults and three calves were observed foraging, and three adults were observed traveling near Drift River. On May 8, two adults were observed 300 m (984 ft) from shore near Tyonek dock, three adults and one juvenile were observed near Drift River.

5.4.3.12 2012 Apache 3D Seismic Program

Apache conducted a 3D seismic program with a marine mammal monitoring and mitigation program between May 6 and September 30, 2012. Seismic surveys were conducted in nearshore and offshore waters during slack tides from multiple vessels. Marine mammal monitoring was conducted from vessels, land platforms, and helicopters or small fixed wing aircraft. PSOs monitored from the seismic and mitigation vessels and land during all day time seismic operations. Aerial overflights were conducted one to two times daily of the project area and surrounding coastline, including the major river mouths to monitor for larger congregations of marine mammals in and around the project vicinity. Passive acoustic monitoring took place from the mitigation vessel during all night time seismic operations and most day time seismic operations.

Six identified species and three unidentified species of marine mammals were observed from the vessels, land, and aerial platforms during the program. The species observed include Cook Inlet beluga whale, harbor seal, harbor porpoise, Steller sea lion, gray whale (*Eschrichtius robustus*), and California sea lion (*Zalophus californianus*). PSOs also observed unidentified species including a large cetacean, pinniped and marine mammal. The gray whale and California sea lion were not included in the IHA, so mitigation measures implemented for these species were implemented at the strictest level.

There were a total of 882 sightings and an estimated 5,232 individuals. Harbor seals were the most frequently observed marine mammals at 563 sightings (~3,471 estimated individuals), followed by beluga whales with 151 sightings (~1,463 estimated individuals), harbor porpoises with 137 sightings (~190 estimated individuals), and gray whales with 9 sightings (9 estimated individuals). Steller sea lions were observed on three separate occasions (~4 estimated individuals) and California sea lions were observed once (~2 estimated individuals).

5.4.3.13 2013 Apache Beluga Surveys

During the summer of 2013 Apache conducted fixed wing surveys for marine mammals along the coastline of upper Cook Inlet. Beluga whale, harbor porpoise (three sightings), and harbor seal were observed. The majority of sightings were harbor seal (919). Seven hundred and eighteen sightings of beluga whale individuals occurred in May (141), June (252), July (294), and August (31). These sightings took place throughout Upper Cook Inlet; including Chickaloon Bay and the Susitna River Delta. Apache is currently conducting marine mammal monitoring during their 2014 program, but results are preliminary and will be published after completion of seismic activities.

5.4.3.14 2013 AEA Beluga Studies

During the summer of 2013 the Alaska Energy Authority, under initial permitting studies for the Susitna-Watana Hydroelectric Project (FERC Project No. 14241) conducted a Cook Inlet Beluga Whale Study (AEA 2013). This study took place with 17 aerial surveys from May 6 to October 11 with surveys spaced around High, Intermediate, and Low Tides. Observers documented 42 beluga whale groups and 722 beluga individuals. Most sightings were classified as nearshore, and none were observed in the Susitna River. No beluga sightings were recorded between September and October. Available results were only preliminary, and no written report has been issued at this time.

5.4.4 Feeding

Beluga whales are opportunistic feeders, foraging at the mouths of rivers and along the benthos. In Cook Inlet, the primary foraging locations for beluga whales are the Susitna River Delta (the Big and Little Susitna Rivers), Eagle Bay, Eklutna River, Ivan Slough, Theodore River, Lewis River, and Chickaloon Bay and River (NMFS 2008a). Cook Inlet belugas feed on a wide variety of prey species, particularly those that are seasonally abundant. Hobbs et al. (2008) presents the most current analysis of stomach contents derived from stranded or harvested belugas in Cook Inlet. This analysis is continuing and provides information on prey availability and prey preferences of Cook Inlet belugas which is summarized below.

In spring, the preferred prey species are eulachon and cod. Other fish species found in the stomachs of belugas may be from secondary ingestion by cods that feed on polychaetes, shrimp, amphipods, mysids, as well as other fish (e.g., walleye pollock and flatfish), and invertebrates.

From late spring and throughout summer most beluga stomachs sampled contained Pacific salmon corresponding to the timing of fish runs in the area. Anadromous smolt and adult fish concentrate at river mouths and adjacent intertidal mudflats (Calkins 1989). Five Pacific salmon species: Chinook, pink, coho, sockeye, and chum spawn in rivers throughout Cook Inlet (Moulton 1997; Moore et al. 2000). Calkins (1989) recovered 13 salmon tags in the stomach of an adult beluga found dead in Turnagain Arm. Beluga hunters in Cook Inlet reported one whale having 19 adult Chinook salmon in its stomach (Huntington 2000). Salmon, overall, represent the highest percent frequency of occurrence of the prey species in Cook Inlet beluga stomachs. This suggests that their spring feeding in upper Cook Inlet, principally on fat-rich fish such as salmon and eulachon, is very important to the energetics of these animals.

In the fall, as anadromous fish runs begin to decline, belugas return to consume fish species (cod and bottom fish) found in nearshore bays and estuaries. Bottom fish include Pacific staghorn sculpin, starry flounder, and yellowfin sole. Stomach samples from Cook Inlet belugas are not available for winter months (December through March), although dive data from belugas tagged with satellite transmitters suggest whales feed in deeper waters during winter (Hobbs et al. 2005), possibly on such prey species as flatfish, cod, sculpin, and pollock.

5.5 Steller Sea Lion

Steller sea lion habitat extends around the North Pacific Ocean rim from northern Japan, the Kuril Islands and Okhotsk Sea, through the Aleutian Islands and Bering Sea, along Alaska's southern coast, and south to California (NMFS 2008c). NMFS reclassified Steller sea lions as two distinct population segments (DPS) under the ESA based on genetic studies and phylogeographical analyses from across the sea lions range (62 FR 24345). The eastern DPS includes sea lions born on rookeries from California north through Southeast Alaska; the western DPS includes those animals born on rookeries from Prince William Sound westward (NMFS 2008c). Steller sea lions occur in Cook Inlet but south of Anchor Point around the offshore islands and along the west coast of the upper Cook Inlet in the bays (Chinitna Bay, Iniskin Bay, etc.) (Rugh et al. 2005a). Portions of the southern reaches of the lower inlet are designated as critical habitat, including a 20-nautical mile buffer around all major haul out sites and rookeries. Rookeries and haulout sites in lower Cook Inlet include those near the mouth of the inlet, which are far south of the project area.

5.5.1 Hearing Abilities

Steller sea lions have similar hearing thresholds in-air and underwater to other otariids. In-air hearing range from 0.250-30 kHz, with a region of best hearing sensitivity from 5-14.1 kHz (Muslow and Reichmuth 2010). The underwater audiogram shows the typical mammalian U-shape. The range of best hearing was from 1-16 kHz. Higher hearing thresholds, indicating poorer sensitivity, were observed for signals below 16 kHz and above 25 kHz (Kastelein et al. 2005).

5.6 Gray Whale

The population of the Eastern North Pacific (ENP) stock of gray whales is estimated to be around 18,017 animals (Wade and Angliss 1997; Carretta et al. 2014). Numbers of gray whales in Cook Inlet are small compared to the overall population, but Apache observers recorded nine sightings of nine individuals (including possible resights of the same animal[s]) from May-July 2012. Of those sightings, seven were observed from project vessels, and two were observed from land; no animals were observed during aerial surveys. Gray whales were not previously recorded in Cook Inlet during NMFS aerial surveys, so they were not expected to be observed during Apache's operations (Lomac-MacNair et al. 2013). Due to the 2012 sightings, Apache has included gray whales in this LOA application but expects few, if any, sightings.

The ENP gray whales observed in Cook Inlet are likely migrating to summer feeding grounds in the Bering, Chukchi, and Beaufort seas, though a small number feed along the coast between Kodiak Island and northern California (Matkin 2009; Carretta et al. 2014). Like other baleen whales, communication and hearing of gray whales are well developed; they can communicate from 20 Hz to 3 kHz, with the most common sounds occurring between 20-200 Hz and rarely above 1500 Hz (Crane and Lashkari 1996).

6.0 Requested Type of Incidental Taking Authorization

The type of incidental taking authorization that is being requested and the method of incidental taking.

Apache requests NMFS promulgate regulations to allow the issuance of Letter of Authorization (LOAs) for the incidental take by harassment (Level B as defined in 50 Code of Federal Regulation [CFR] 216.3) of a small number of marine mammals during seismic survey operations in Cook Inlet. The operations outlined in Sections 2 and 3 have the potential to result in incidental takes of marine mammals by acoustic exposure during seismic operations. The effects will depend on the species and received level of the sound (Section 8). Temporary disturbance or localized displacement reactions may potentially occur. With implementation of the mitigation and monitoring measures described in Sections 12 and 14, no takes by injury or mortality (Level A) are anticipated, and a minimal number of takes by disturbance (Level B) are expected.

7.0 Number of Incidental Takes by Activities

By age, sex, and reproductive condition, the number of marine mammals [by species] that may be taken by each type of taking, and the number of times such takings by each type of taking are likely to occur.

The proposed seismic survey operations outlined in Sections 2 and 3 have the potential to temporarily disturb or displace small numbers of marine mammals in Cook Inlet. These potential effects, as summarized in Section 8, will not exceed MMPA Level B harassment, as defined by 30 CFR 213.6. The mitigation measures to be implemented during the survey are based on Level B harassment criteria using the 160 dB re 1 µPa rms threshold defined below. No take by injury or death is anticipated with implementation of the mitigation and monitoring measures. The following sections provide information on the applicable noise criteria and a description of the methods used to calculate numbers of marine mammals that may be potentially encountered during the seismic program.

7.1 Applicable Noise Criteria

Under the MMPA, NMFS has defined levels of harassment for marine mammals. Level A harassment is defined as "…any act of pursuit, torment, or annoyance which has the potential to injure a marine mammal or marine mammal stock in the wild." Level B harassment is defined as "…any act of pursuit, torment, or annoyance which has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering." The current Level A (injury/exclusion) threshold for impulse noise is 180 dB re 1 µPa rms for cetaceans and 190 dB re 1 µPa rms for pinnipeds. The current Level B (disturbance) threshold for impulse noise is 160 dB re 1 µPa rms for cetaceans and pinnipeds. NMFS is developing new science-based thresholds to improve and replace the current generic exposure level thresholds, but the criteria have not been finalized (http://www.nmfs.noaa.gov/pr/acoustics/guidelines.htm).

7.2 Sound Source Verification and Calculation of 24-Hour Acoustic Footprints

In July of 2011, JASCO Applied Sciences (JASCO) developed a computer model to predict 24-hour acoustic footprints of airgun arrays for Apache's planned Cook Inlet seismic surveys. The modeling study report is attached as Appendix C. The modeled results account for the operation over a 24-hour period, including slack tide-only operations and longest seismic source line. In late April/early May 2012, SSV was conducted of the various airgun configurations at different water depths. The results of the SSV (Appendix D) indicated the largest 160 dB re 1 μPa (rms) ensonified area for the three different aspects of a 2,400 in^3 airgun array was 9.50 km.

In 2014, Seiche Measurements Ltd. (Seiche) conducted SSV testing on the 1,760 in^3 array. The full SSV report is provided in Appendix E, and a comparative summary of the 1,760 in^3 and 2,400 in^3 arrays is provided in Appendix F. The exclusion zones derived from the SSV results will be used for mitigation and monitoring (discussed in Section 12 and 14) and specified in each annual application for an LOA according to the airgun array size to be used.

The JASCO model considered seismic survey activities at nearshore locations at the sides of Cook Inlet having sloping bottoms and in the Inlet's main channel where depth is relatively constant. The nearshore locations were sub-divided into three depth intervals of 5-21 m (16-69 ft), 21-38 m (69-125 ft), and 38-54 m (125-177 ft). The channel scenario had constant water depth 80 m (262 ft) to correspond approximately with the mean channel depth over the region of Cook Inlet that Apache plans to survey. The nearshore survey depth interval subdivisions are based on the zones that can be surveyed in 24-hour periods based on anticipated nominal survey line length: 16.1 km (10 mi), and survey line spacing: 503 m (1,650 ft).

Adjacent lines will be surveyed sequentially. Apache estimates that it can complete 12-14 survey lines per day based on a normal survey vessel speed of 3.5 knots (4 miles per hour [mph]). The depth intervals listed above each correspond with 14 adjacent parallel lines based on the rate of depth increase with distance from shore. The anticipated survey effort included in the acoustic model was provided to JASCO for the first IHA and is considered a worst-case effort. The different depth intervals were considered separately because the size of the airgun array sound footprint varies with water depth.

The largest possible airgun array configuration of 2,400 in^3 was considered by the modeling study to provide conservative estimates of noise footprints; smaller arrays may be used and those would produce smaller footprints. A comparison summary of the 1,760 in^3 and 2,400 in^3 arrays is provided in Appendix F.

The nearshore modeling scenarios were examined by placing the 2,400 in^3 airgun array at three distances offshore corresponding with water depths: 5, 25, and 45 m (16, 82, and 148 ft). For each array position, the model predicted distances to the 160 dB re 1 µPa rms threshold in multiple directions. These distances were subsequently interpolated to predict threshold distances for survey array positions at all depths between 5 m (16 ft) and 54 m (177 ft) depth. The deep channel survey scenario, with constant water depth of 80 m (262 ft), was modeled to predict the distances in the endfire and broadside directions relative to the array that sound levels attenuated to 160 dB re 1 µPa rms.

The 24-hour composite acoustic footprints of the 2,400 in^3 airgun array were calculated from the footprints of the individual survey lines. Each survey line footprint was estimated using a rectangle that encompassed the 160 dB broadside (inshore and offshore directions) and endfire (along-shore) extents for all airgun pulses on that line. The union of the 14 survey line footprints created the 24-hour composite acoustic footprint. The union of the single line footprints is smaller than their sum because of overlap.

7.2.1 Nearshore Survey Results

The distances to the 160, 180, and 190 dB re 1 µPa rms sound level thresholds for the nearshore survey locations are given in Table 2. Distances correspond to the three transects modeled at each site in the onshore, offshore, and parallel to shore directions. To estimate take, Apache used the most conservative (largest) value from each category in Table 2. The 160 dB re 1 µPa footprints for one day of nearshore surveying in shallow, mid-depth, and deep water are shown in Figure 15; the corresponding areas of the footprints are listed in Table 3.

Table 2. Distances to Sound Level Thresholds for the Nearshore Surveys

Sound Level Threshold (dB re 1 µPa)	Water Depth at Source Location (m)	Distance in the Onshore Direction (km)	Distance in the Offshore Direction (km)	Distance in the Parallel to Shore Direction (km)
160	5	1.03	4.73	2.22
	25	5.69	7.77	9.5
	45	6.75	5.95	9.15
180	5	0.46	0.6	0.54
	25	1.06	1.07	1.42
	45	0.7	0.83	0.89
190	5	0.28	0.33	0.33
	25	0.35	0.36	0.44
	45	0.1	0.1	0.51

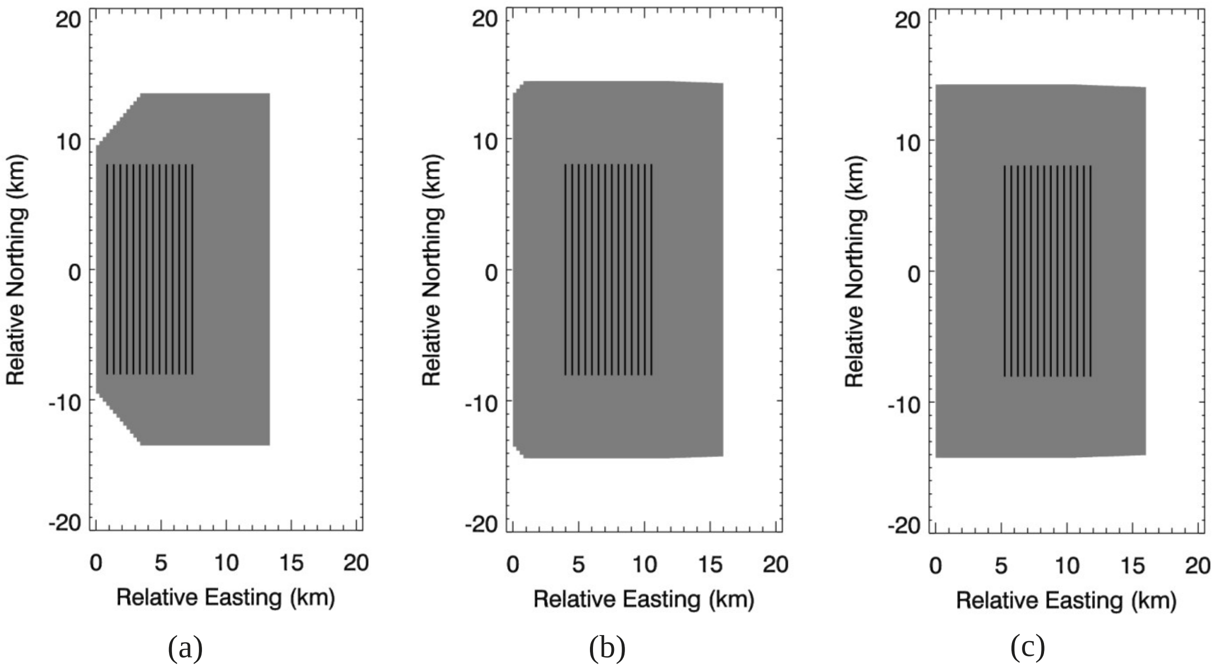


Figure 15. Daily footprints for (a) shallow, (b) mid-depth, and (c) deep water nearshore surveys. The ensonified areas are shown in gray and survey lines are shown in black.

Table 3. Areas Ensonified to 160 dB re 1 μPa for Nearshore Surveys in 24 Hours

Nearshore Survey Depth Classification	Depth Range (m)	Area Ensonified to 160 dB re 1 μPa (km^2)
Shallow	5-21	462
Mid-depth	21-38	629
Deep	38-54	623

7.2.2 Channel Survey Results

The distances to the 160, 180, and 190 dB re 1 μPa rms sound level thresholds for the channel surveys are shown below in Table 4. Distances correspond to the broadside and endfire directions. The 160 dB re 1 μPa rms footprint for 24 hours of seismic survey in the inlet channel is shown in Figure 16; the corresponding area of the footprint is 517 km^2.

Table 4. Distances to Sound Level Thresholds for the Channel Surveys

Sound Level Threshold (dB re 1 μPa)	Water Depth at Source Location (m)	Distance in the Broadside Direction (km)	Distance in the Endfire Direction (km)
160	80	5.14	7.33
180	80	0.91	0.98
190	80	0.15	0.18

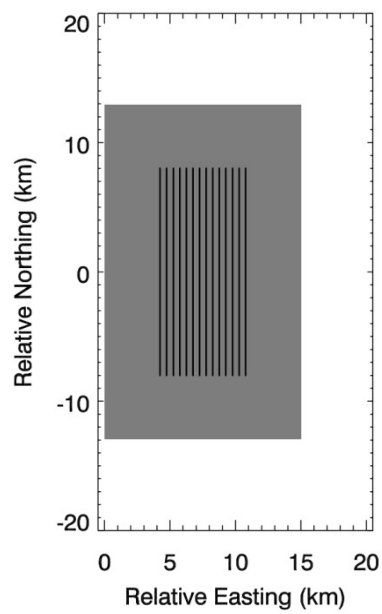


Figure 16. Daily footprint for channel surveys. The ensonified area is shown in gray and the survey lines are shown in black.

7.2.3 Positioning pinger

As described in Section 2.2.2, the maximum source level of the pinger is 188 dB re μPa at 1 m rms (at 33 - 55 kHz). Assuming a simple spreading loss of 20 log R (where R is radius) with a source level of 188 dB, the distance to the 190, 180, and 160 dB isopleths would be 1, 3, and 25 m (3.28, 9.8, and 82 ft), respectively. This spreading loss is appropriate for high-frequency pulsed systems. The reason is that the multipaths (direct path, surface reflection, bottom reflection, etc.) of short duration pulses arrive at the receivers spaced in time. The rms level therefore should be computed for the strength of the strongest multipath, which will be the direct path. The use of 20 log R is fully appropriate because this path does not interact with surface or bottom (otherwise it would have an even higher coefficient than 20).

7.3 Estimates of Marine Mammal Density

During the intergovernmental consultation process for Apache's second IHA application, NMFS consulted with the NMML for an independent review of the marine mammal density in Cook Inlet. The NMML responded with a predictive beluga habitat model (Goetz et al. 2012a). For consistency purposes, the NMML beluga model was used to predict beluga takes for this petition, and other marine mammal takes were predicted using traditional techniques described below.

To develop NMML's estimated densities of belugas, Goetz et al. (2012a) developed a model based on aerial survey data, depth soundings, coastal substrate type, environmental sensitivity index, anthropogenic disturbance, and anadromous fish streams to predict beluga densities throughout Cook Inlet. The result of this work is a beluga density map of Cook Inlet, which easily sums the belugas predicted within a given geographic area.

Estimated densities of other marine mammals in the proposed project area were estimated from the annual aerial surveys conducted by NMFS for Cook Inlet beluga whale between 2000 and 2012 in June (Rugh et al. 2000, 2001, 2002, 2003, 2004b, 2005b, 2006, 2007; Shelden et al. 2008, 2009, 2010, 2012; Hobbs et al. 2011). These surveys were flown in June to collect abundance data of beluga whales, but sightings of other marine mammals are also reported. Although these data are only collected in one month each year, these surveys provide the best available relatively long term data set for sighting information in the proposed project area. The general trend in marine mammal sighting is that beluga whales and harbor seals are seen most frequently in upper Cook Inlet, with higher concentrations of harbor seals near haul out sites on Kalgin Island and of beluga whales near river mouths, particularly the Susitna River. The other marine mammals of interest for this petition are observed infrequently in upper Cook Inlet and more commonly in lower Cook Inlet. In addition, these densities are calculated based on a relatively large area that was surveyed, much larger than the proposed seismic area. Furthermore, these annual surveys are conducted only in June (numbers from August surveys were not used because the area surveyed was not provided), so it does not account for seasonal variations in distribution or habitat use of each species. Therefore, the use of these data to estimate density is extremely conservative and likely provides much higher density estimates of these animals in the project area.

Table 5 provides a summary of the results of each annual survey conducted in June from 2000 to 2012. The total number of individuals sighted for each survey by year is reported, as well as total hours for the entire survey and total area surveyed. To estimate density of marine mammals, total number of individuals (other species) observed for the entire survey area by year (surveys usually last several days) was divided by the total number of hours for each aerial survey by the approximate total area surveyed for each year (density = individuals/hour/km^2). As noted previously, the total number of animals observed for the entire survey includes both lower and upper Cook Inlet, so the total number reported and used to calculate density is higher than the number of marine mammals anticipated to be observed in the project area. In particular, the total number of harbor seals observed on several surveys is very high due to several large haul outs in lower and middle Cook Inlet.

Table 5. Sightings of Marine Mammals from NMFS Annual Aerial Surveys.

Location	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Other Species*													
Gray Whale	**2**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Harbor seal	**1800**	**1485**	**1606**	**974**	**956**	**1087**	**1798**	**1474**	**2037**	**1415**	**1156**	**1811**	**1812**
Harbor porpoise	**29**	**25**	**0**	**0**	**100**	**2**	**0**	**4**	**6**	**86**	**10**	**30**	**11**
Killer whale	**0**	**15**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**33**	**0**	**9**
Steller sea lion	**10**	**35**	**54**	**77**	**1**	**104**	**83**	**0**	**75**	**39**	**1**	**100**	**65**
Survey Details													
Number of total survey hours (hrs)	43	55	45	61	45	54.5	58.4	47.2	47.7	39.4	48.4	47	53
Total area surveyed (km^2)	6500	5200	5244	5100	6000	5500	6723	5255	7172	5766	6120	6790	6219
Density Estimates (no. animals / no. survey hrs / km^2 surveyed)													
Gray whale**	<0.00001	<0.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Harbor seal**	0.00644	0.00519	**0.00681**	0.00313	0.00354	0.00363	0.00458	0.00594	0.00595	0.00623	0.00390	0.00567	0.005497
Harbor porpoise**	0.00010	0.00009	0.00000	0.00000	0.00037	0.00001	0.00000	0.00002	0.00002	**0.00038**	0.00003	0.00009	0.000033
Killer whale**	0.00000	0.00005	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	**0.00011**	0.00000	0.000027
Steller sea lion**	0.00004	0.00012	0.00023	0.00025	0.00000	**0.00035**	0.00021	0.00000	0.00022	0.00017	0.00000	0.00031	0.000197

Bold numbers indicate highest counts per year per species and used in density estimates.

* Counts indicate total observed per year

** Total number observed animals per year were used to estimate density

Table 6. Summary of Density Estimates of Marine Mammals

	Density	
Species	**Maximum**	**Average**
Gray whale*	<0.00001	<0.00001
Harbor seal*	0.00681	0.00512
Harbor porpoise*	0.00038	0.00009
Killer whale*	0.00011	0.00001
Steller sea lion*	0.00035	0.00016

Density = no. animals / survey effort (hrs) / area surveyed (km^2)

* Total number observed animals per year were used to estimate density on Table 5.

7.4 Calculation of Takes

In October 2012, plaintiffs (Native Village of Chickaloon et al.) requested motion for a summary judgment from the US District Court for the District of Alaska, challenging NMFS methods for estimating takes issued under the first Apache IHA (effective April 30, 2012 – April 30, 2013). The court concluded that NMFS take calculations were erroneous because they combined corrected population abundance figures with uncorrected (raw) survey density estimates (USDC 2013). The raw survey density estimates are derived from sightings during monthly aerial surveys and provide the best long-term data for sightings in the project area, but they do not correct for missed animals or seasonal variations in distribution (NMFS 2013b).

During the second Apache IHA application process a correction factor was applied to the sightings data, which prompted NMFS to seek a review from the NMML. NMML developed and applied a predictive habitat model (Goetz et al. 2012a) of beluga density estimates to Apache's 2013 survey area and found that a total of 21.5 belugas could be taken by Level B harassment, which was lower than Apache's original estimates (NMFS 2013b).

As a result of discussions with NMFS, Apache proposes to use the NMML model (Goetz et al. 2012a) for the calculation of takes in this petition. During each annual application for a LOA, Apache will coordinate with NMFS to develop an operational survey area (including the 160-dB ensonification buffer) that results in less than 30 calculated beluga whale takes under the NMML model. The 30 beluga take limit was used in the initial Apache IHA and it continues to withstand legal review as qualifying as small numbers for the Cook Inlet population. This will allow Apache to prioritize survey locations annually, in response to local weather, ice, and operational constraints. In addition, NMFS will have the opportunity to apply the most recent beluga density model and data to ensure the annual operational survey area does not exceed 30 calculated takes.

Apache reasserts their goal is to have no actual beluga takes during the entire survey period covered under this petition by strict adherence to the mitigation measures described in this request. The LOAs are expected to authorize observed takes during the operations, based on calculated takes derived from the NMML model. While the NMML model provides informative densities for operational planning, the authorized takes will be for observed beluga whale takes, not predicted or calculated takes.

Apache will attempt to survey the annually authorized area in a manner that avoids seasonal beluga whale concentrations. If the annual operation area has been completely surveyed with less than 30 observed takes, Apache may continue surveying within the area requested in this petition until 30 observed takes are documented.

The estimated or projected number of other Cook Inlet marine mammals that may be potentially disturbed during the seismic surveys per year was calculated by multiplying the density estimates discussed in the previous section (individuals/hr/km^2) by the anticipated area ensonified by levels ≥160 dB re µPa rms (Appendix C, Appendix D) by the expected number of seismic survey days per year in the project area. As discussed in Section 2, Apache anticipates that a crew will collect seismic data 8- 12 hours per day over approximately 160 days during the course of eight to nine months per year. It is assumed that during these 160 days, 100 days would be working in the offshore region and 60 days in the shallow, intermediate, and deep nearshore region. Of those 60 days in the nearshore region, 20 days would be in each depth. It is important to note that environmental conditions (such as ice, wind, fog) will play a significant role in the actual operating days; therefore, these estimates are conservative in order to provide a basis for probability of encountering these marine mammal species in the project area.

The number of estimated takes by disturbance was calculated using the following assumptions:

- The number of nearshore and shallow water survey days per year is 20 and daily acoustic footprint is 462 km^2 (178 mi^2).
- The number of nearshore and intermediate water depth survey days per year is 20 and daily acoustic footprint is 629 km^2 (243 mi^2).
- The number of nearshore and deep water depth survey days per year is 20 and daily acoustic footprint is 623 km^2 (241 mi^2).
- The number of offshore survey days per year is 100 and daily footprint is 517 km^2 (200 mi^2).

Table 7 shows the estimated maximum and average annual takes by species for the program with the methods and assumptions outlined above.

Table 7. Maximum and Average Encounter Probability (Maximum Level B Take Estimates) per Species per year

	Shallow		Intermediate		Deep		Offshore		Annual Total	
Area Ensonified (km^2)	**462**		**629**		**623**		**517**		**2231**	
Survey days	**20**		**20**		**20**		**100**		**160**	
Species	**max**	**avg**	**max**	**avg**	**max**	**avg**	**max**	**avg**	**max**	**Avg**
Gray whales	0.09	0.09	0.13	0.13	0.12	0.12	0.52	0.52	0.86	0.86
Harbor seals	62.9	47.3	85.6	64.4	84.8	63.8	351.9	264.5	585.2	439.9
Harbor porpoises	3.5	0.8	4.8	1.1	4.7	1.1	19.6	4.5	32.5	7.6
Killer whales	1.0	0.1	1.4	0.2	1.4	0.2	5.8	0.8	9.6	1.3
Steller sea lions	3.2	1.5	4.4	2.0	4.3	2.0	17.9	8.4	29.8	13.9

Shallow water = 5-21 m
Intermediate water = 21-38 m
Deep water = 38-54 m
Take estimates =density (from Table 6) * area ensonified ≥ 160 dB re 1 µPa rms from JASCO (Appendix C) * no.of days estimated to be seismically surveyed

Table 7 identifies the worst-case probability per year of encountering these marine mammal species within the 160 dB exclusion zone during the survey and does not account for seasonal distribution of these species, haul outs of harbor seals and Steller sea lions, or the rigorous mitigation and monitoring techniques implemented by Apache to reduce Level B takes to all species. The following text describes each point further.

7.4.1 Seasonal Distribution

Apache conducted regular aerial surveys for Cook Inlet beluga whales in 2012 and 2013; and while conducting operations has an extensive working knowledge of where belugas are located. Both of these sources confirm that there are dramatic shifts in beluga distribution throughout the year; and that these shifts must be incorporated into operational planning. To accomplish Apache's goal of zero beluga takes, Apache will incorporate seasonal considerations of beluga density into the prioritization of their seismic program, in addition to other factors such as weather, ice conditions, and operations.

The NMML model of beluga distribution is best for summer seasons. Hobbs et al. (2005) was able to incorporate August to March seasonal movements into their study, but did not provide density modeling. Using the Hobbs et al. (2005) data, beluga occupation south of the forelands can be summarized as being minimal in August and September. Hobbs et al. (2005) also suggests that belugas are most widely distributed throughout Cook Inlet in February and March, resulting in the lowest beluga density north of the forelands. To minimize potential impacts to belugas, seismic work will be conducted in a manner that will attempt to avoid seasonal beluga whale concentrations. .

For other marine mammals, data used to estimate probability of sightings for Cook Inlet are based on a short aerial surveys conducted primarily in June of each year. This aerial survey does not take into account that marine mammal species are not evenly distributed across Cook Inlet in these numbers and that animals seen in June at those levels may not be observed in that same area two months later. Because there are no other systematic surveys for Cook Inlet that provide the level of detail for these years, this is still the best available data for estimating takes. In particular, killer whales, harbor porpoises, and Steller sea lions are expected to be observed more frequently in lower and mid-Cook Inlet; while beluga whales are more likely to be following the salmon and eulachon fish runs within Upper Cook Inlet.

7.4.2 Pinniped Haul Outs

Seismic surveys in the Trading Bay region have resulted in numerous sightings of individual harbor seals. Apache does not anticipate encountering large haul outs of seals or Steller sea lions in the project area, but expects to continue to observe curious individual harbor seals; particularly during large fish runs in the various rivers draining into Cook Inlet. These density estimates are skewed by the numbers observed in large haul outs on the aerial surveys; seals on land would not be exposed to in-water sounds during that time. Seals in the water usually travel in small groups or as singles. Therefore, although Table 7 indicates an annual average of 440 and maximum of 586 seals to be observed, it is highly unlikely that those numbers of seals would be taken by harassment during seismic operations.

For many of the same reasons discussed above for harbor seals, the number of actual takes by harassment of Steller sea lions are expected to be much lower than the annual average of 14 and maximum of 30. In all of the NMFS aerial surveys, no Steller sea lions were observed in upper Cook Inlet. Less than five Steller sea lions have been observed by the Port of Anchorage monitoring program, and those observed have been single, juvenile animals (likely male). Apache annually anticipates less than five Steller sea lions in the project area.

7.4.3 Monitoring and Mitigation

As described in detail in Sections 12 and 14, Apache has implemented a rigorous monitoring and mitigation program to reduce Level B harassment. Apache implements a power down (or shut down if necessary) of air gun operations if any beluga whales are sighted within or approaching the 160 dB exclusion zone and have committed to not taking by harassment more than 30 beluga whales in one year. The maximum probable number of sightings for beluga whales is not expected to be exposed to seismic air guns at harassment level because of the rigorous mitigation program. Given that belugas are usually transiting from one feeding area to another in lower concentrations, these estimates appear to be reasonable in assessing probability of beluga whales potentially observed.

Furthermore, the total number of days actually surveying near river mouths is much lower than the 160 days used to estimate takes in these different water depths, so this probability sighting table is extremely conservative. Therefore, due to actual number of days and hours likely to be operating airguns near river mouths and the strict monitoring and mitigation measures to be used when operating near rivers, the actual annual number of takes by harassment estimated is expected to be much lower than the numbers in Table 7.

7.5 Summary of Requested Takes

Based on the discussion and estimates above, Apache requests the following number of annual observed takes by harassment by species for the project area (Table 8). Apache was authorized these same take levels from March 1, 2013 through March 1, 2014. Apache asks for the same numbers for all species based on the numbers of sightings and shut downs already implemented in 2012. It is important to note that Apache understands and is not asking for additional takes per year, but will continue to operate with the assumption that 30 beluga whale takes (and relevant other species) will be authorized in a 1-year period regardless of the area of operations.

The abundance of the populations, as summarized in Section 4, is also provided with the calculated percent of the population that will be temporarily behaviorally disturbed during seismic operations. As shown in the table, the percent of all species annually requested to be taken by harassment is less than 10 percent of the population for all of the species, and less than 1 percent for all except the beluga whales. Therefore, Apache anticipates there will be no more than a negligible impact on small numbers of marine mammals during the seismic operations.

Table 8. Annual Requested Number of Takes

Species	Annual Number of Requested Takes	Population Abundance	Percent of Population
Beluga whales	30	283	10.60%
Gray whale	2	18,017	0.01%
Harbor seals	440	22,900	1.92%
Harbor porpoises	20	25,987	0.08%
Killer whales	10	1,123	0.89%
Steller sea lions	20	45,916	0.04%

Note: population abundance summarized in Section 3

8.0 Description of Impact on Marine Mammals

The anticipated impact of the activity upon the species or stock.

8.1 General Effects of Noise on Marine Mammals

Marine mammals use hearing and sound transmission to perform vital life functions. Introducing sound into their environment could be disrupting to those behaviors. Sound (hearing and vocalization/ echolocation) serves four primary functions for marine mammals, including: 1) providing information about their environment, 2) communication, 3) prey detection, and 4) predator detection. The distances to which airgun noise associated with the Cook Inlet Seismic Program are audible depend upon source levels, frequency, ambient noise levels, the propagation characteristics of the environment, and sensitivity of the receptor (Richardson et al. 1995).

The effects of sounds from airguns on marine mammals might include one or more of the following: tolerance, masking of natural sounds, behavioral disturbance, and temporary or permanent hearing impairment, or non-auditory physical effects (Richardson et al. 1995). In assessing potential effects of noise, Richardson et al. (1995) has suggested four criteria for defining zones of influence. These zones are described below from greatest influence to least:

Zone of hearing loss, discomfort, or injury – the area within which the received sound level is potentially high enough to cause discomfort or tissue damage to auditory or other systems. This includes temporary threshold shifts (TTS, temporary loss in hearing) or permanent threshold shifts (PTS, loss in hearing at specific frequencies or deafness). Non-auditory physiological effects or injuries that theoretically might occur in marine mammals exposed to strong underwater sound include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage.

Zone of masking – the area within which the noise may interfere with detection of other sounds, including communication calls, prey sounds, or other environmental sounds.

Zone of responsiveness – the area within which the animal reacts behaviorally or physiologically. The behavioral responses of marine mammals to sound is dependent upon a number of factors, including: 1) acoustic characteristics the noise source of interest; 2) physical and behavioral state of animals at time of exposure; 3) ambient acoustic and ecological characteristics of the environment; and 4) context of the sound (e.g., whether it sounds similar to a predator) (Richardson et al. 1995; Southall et al. 2007). However, temporary behavioral effects are often simply evidence that an animal has heard a sound and may not indicate lasting consequence for exposed individuals (Southall et al. 2007).

Zone of audibility – the area within which the marine mammal might hear the noise. Marine mammals as a group have functional hearing ranges of 10 Hz to 180 kHz, with best thresholds near 40 dB (Ketten 1998; Kastak et al. 2005; Southall et al. 2007). These data show reasonably consistent patterns of hearing sensitivity within each of three groups: small odontocetes (such as the harbor porpoise), medium-sized odontocetes (such as the beluga and killer whales), and pinnipeds (such as the harbor seal and Steller sea lion). Hearing capabilities of the species included in this Application are discussed in Section 4.0. There are no applicable criteria for the zone of audibility due to difficulties in human ability to determine the audibility of a particular noise for a particular species.

8.1.1 Potential Effects of Airgun Sounds

The following text describes the potential impacts on marine mammals due to seismic activities. Due to the mitigation measures discussed in Sections 12 and 14, it is unlikely there would be any temporary or especially permanent hearing impairment, or non-auditory physical effects on marine mammals. In addition, most of nearshore area of Cook Inlet is a poor acoustic environment because of its shallow depth, soft bottom, and high background noise from currents and glacial silt which greatly reduces the distance sound travels (Blackwell and Greene 2002).

8.1.1.1 Tolerance

Studies have shown that pulsed sounds from airguns are often readily detectable in the water at distances of many kilometers, but they do not necessarily cause behavioral disturbances. Numerous studies have shown that marine mammals at distances over a few kilometers from operating seismic vessels often show no apparent response. That is often true even when pulsed sounds must be readily audible to the animals based on measured received levels and the hearing sensitivity of that mammal group. Although various baleen whales, toothed whales, and (less frequently) pinnipeds have been shown to temporarily react behaviorally to airgun pulses under some conditions, at other times they have shown no overt reactions. In general, pinnipeds and small odontocetes are more tolerant of exposure to airgun pulses than baleen whales.

8.1.1.2 Masking

Masking of marine mammal calls and other natural sounds are expected to be limited in the presence of seismic noise, although there are very few specific data of relevance. Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999; Nieukirk et al. 2004; Di Iorio and Clark 2010). Masking effects of seismic pulses are expected to be negligible in the case of the odontocete cetaceans, given the intermittent nature of seismic pulses. Also, the sounds important to small odontocetes are predominantly at much higher frequencies than are airgun sounds. Therefore, the potential problem of auditory masking for beluga whales is diminished by the small amount of overlap between frequencies produced by seismic and other industrial noise (<1 kHz) and frequencies which beluga whales call (0.26-20 kHz) and echolocate (40-60 kHz and 100-120 kHz; Blackwell and Greene 2002). Additionally, beluga whales have been known to change their vocalizations in the presence of high background noise possibly to avoid masking calls (Au et al. 1985; Lesage et al. 1999; Scheifele et al. 2005).

8.1.1.3 Disturbance Reactions

Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, environmental conditions, and many other factors (Richardson et al. 1995). If a marine mammal does react briefly to an underwater sound by changing its behavior or moving a short distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, which is not anticipated in the proposed seismic program, impacts on the animals could be significant. Given the many uncertainties in predicting the quantity and types of impacts of sound on marine mammals, it is common practice to estimate how many mammals were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound to assess behavioral disturbance. However, this procedure likely overestimates the numbers of marine mammals that are affected in some biologically important manner.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically important but unknown degree by a seismic program are based on behavioral observations during studies of several species. However, information is largely lacking for many species including those species likely to occur in the project areas. Detailed studies have been done on other species found elsewhere in Alaska waters including gray whales, bowhead whales, and ringed seals. The criteria established for these marine mammals, which are applied to others are conservative and have not been demonstrated to significantly affect individuals or populations of marine mammals in Alaska waters. Therefore, the effect of the seismic program on the behavior of marine mammals should be no more than negligible for reasons stated earlier.

Toothed Whales. Little systematic information is available about reactions of beluga whales, killer whales, and harbor porpoise to noise pulses. Beluga whales exhibit changes in behavior when exposed to strong, pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002a; Finneran et al. 2002b). However, the animals tolerated high received levels of sound (peak–peak level >200 dB re 1 μPa) before exhibiting aversive behaviors (Richardson et al. 1995). Some belugas summering in the Eastern Beaufort Sea may have avoided the specific area of seismic operations (two arrays with 24 airguns per array), which used a larger array than the proposed program (two arrays of 16 airguns per array), by 10 to 20 km (6.2 to 12.4 mi), although belugas occurred as close as 1,540 m (5,052 ft) to the line of seismic operations (Miller et al 2005). Observers stationed on seismic vessels operating off the United Kingdom from 1997 - 2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003; Gordon et al. 2004). Killer whales were found to be significantly farther from large airgun arrays during periods of shooting compared with periods of no shooting. The displacement of the median distance from the array was ~0.5 km (0.3 mi) or more. Killer whales also appear to be more tolerant of seismic shooting in deeper water. Killer whales are rare to uncommon in the inlet, therefore, the planned seismic program should have no more than a negligible impact on killer whales and no effect on the population. Harbor porpoises are rarely sighted, but have been detected acoustically throughout the inlet. However, based on the relatively few animals observed, the project should have no more than a negligible impact and no effect on the population.

Pinnipeds. While there are no published data on seismic effect on sea lions or harbor seals, anecdotal data and data on arctic seals indicate that sea lions and other pinnipeds generally tolerate strong noise pulses (Richardson et al. 1995). Monitoring studies in the Alaskan and Canadian Beaufort Sea during 1996 - 2002 provided considerable information regarding behavior of arctic seals exposed to seismic pulses (Miller et al. 2005; Harris et al. 2001; Moulton and Lawson 2002). These seismic projects usually involved arrays of 6 to 16 with as many as 24 airguns with total volumes 560 to 1,500 in^3. The combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings tended to be farther away from the seismic vessel when the airguns were operating than when they were not (Moulton and Lawson 2002). However, these avoidance movements were relatively small, on the order of 100 m (328 ft) to (at most) a few hundred meters, and many seals remained within 100 to 200 m (328 to 656 ft) of the trackline as the operating airgun array passed by them. Seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997. Miller et al. (2005) also reported higher sighting rates during non-seismic than during line seismic operations, but there was no difference for mean sighting distances during the two conditions nor was there evidence ringed or bearded seals were displaced from the area by the operations. The operation of the airgun array had minor and variable effects on the behavior of seals visible at the surface within a few hundred meters of the array. The behavioral data from these studies indicated that some seals were more likely to swim away from the source vessel during periods of airgun operations and more likely to swim towards or parallel to the vessel during non-seismic periods. No consistent relationship was observed between exposure to airgun noise and proportions of seals engaged in other recognizable behaviors, e.g. “looked” and “dove”. Such a relationship might have occurred if seals seek to reduce exposure to strong seismic pulses, given the reduced airgun noise levels close to the surface where “looking” occurs (Miller et al. 2005; Moulton and Lawson 2002).

Consequently, by using the responses of bearded, ringed, and spotted seals (least amount of data on reaction to seismic operations) to seismic operations as surrogates for harbor seals and sea lions, it is reasonable to conclude that the relatively small numbers relative to the population size (see Table 8) of harbor seals and the even smaller numbers of Steller sea lions possibly occurring in the project area during seismic operations are not likely to show a strong avoidance reaction to the proposed airgun sources. Pinnipeds frequently do not avoid the area within a few hundred meters of operating airgun arrays, even for airgun arrays much larger than that planned for the proposed project (e.g., Harris et al. 2001). Reactions are expected to be very localized and confined to relatively small distances and durations, with no long-term effects on individuals or populations.

8.1.1.4 Strandings and Mortality

There is no evidence in the literature that airgun pulses can cause serious injury, death, or stranding of marine mammals even in the case of larger airgun arrays than planned for the proposed program (76 FR 58473). Seismic surveys have been referenced as possible causes of marine mammal strandings (Engel et al. 2004; Taylor et al. 2004), but the evidence is inconclusive (71 FR 43112). While strandings have been associated with military mid-frequency sonar pulses (Jepson et al. 2003; Fernández et al. 2004; Hildebrand 2005), Apache does not plan to use such sonar systems during the Cook Inlet Seismic Program. Seismic pulses and military mid-frequency sonar pulses are quite different. Sounds produced by airgun arrays are broadband with most of the energy below 1 kHz. In addition, strandings associated with sound exposure have not been documented in Cook Inlet (76 FR 58473).

8.1.1.5 Noise Induced Threshold Shift

There is sometimes confusion when reporting sound levels. It is important to not only say "dB" but to also add the reference level. This is often written as "dB re 1 μPa" for sounds in water that are measured relative (re) to 1 μPa and "dB re 20 μPa" for sounds in air that are measured relative (re) to 20 μPa. All sound measurements in this document are for measurements made in water, and are specified in terms of dB re 1 μPa.

The different references in air and water leads to confusion not only because the reference is different by a factor of 20, but also because the sound intensity is a function of both the density of the medium (water and air are obviously different), and the velocity of sound in the medium (air at about 350 m/sec and water at about 1,500 m/sec). The net result of this is that sound levels expressed in dB in water, are about 60 dB less (61.5dB) than the same dB levels in air. A 60-dB difference in relative intensity represents a million-fold difference in power. Sound levels of 120 dB (re 1 μPa) in water are roughly equivalent to sound levels of 60 dB (re 20 μPa) in air. A sound level of 60 dB re 20 μPa in air is roughly equivalent to the level of sound in conversational speech.

Animals exposed to intense sound may experience reduced hearing sensitivity for some period of time following exposure. This increased hearing threshold is known as noise induced threshold shift (TS). The amount of TS incurred in the animal is influenced by a number of noise exposure characteristics, such as amplitude, duration, frequency content, temporal pattern, and energy distribution (Kryter 1985; Richardson et al. 1995; Southall et al. 2007). It is also influenced by characteristics of the animal, such as behavior, age, history of noise exposure and health. The magnitude of TS generally decreases over time after noise exposure and if it eventually returns to zero, it is known as TTS. If TS does not return to zero after some time (generally on the order of weeks), it is known as “permanent threshold shift” (PTS). Temporary threshold shift is not considered to be auditory injury and does not constitute “Level A Harassment” as defined by the MMPA. Sound levels associated with TTS onset are generally considered to be below the levels that will cause PTS, which is considered to be auditory injury.

Temporary threshold shift has been studied in captive odontocetes and pinnipeds (reviewed in Southall et al. 2007). Data are available for three cetacean species (bottlenose dolphin, *Tursiops truncatus*; beluga whale, and harbor porpoise) and three pinniped species (harbor seal, California sea lion, *Zalophus californianus*; Northern elephant seal, *Mirounga angustirostris*). However, these data have all been collected from captive animals and no documentation exists of TTS or PTS in free ranging marine mammals exposed to airgun pulses. Inner ears of beluga and bowhead whales examined shortly after being taken in subsistence hunts show little and no evidence of auditory trauma sustained pre-mortem. Beluga whales show some acoustic trauma, though not substantial enough to have caused deafness and not attributed to a specific sound source (Thewissen et al. 2011).

The current NMFS policy regarding exposure of marine mammals to impulsive sound is that cetaceans should not be exposed to impulsive sounds >180 dB re 1 µPa rms and that pinnipeds should not be exposed to impulsive sounds >190 dB re 1µPa rms (NMFS 2000). These criteria were established before information was available about minimum received levels of sound that would cause auditory injury in marine mammals. They are likely lower than necessary and are intended to be precautionary estimates below which no physical injury will occur (Southall et al. 2007). Many marine mammal species avoid ships and/or seismic operations. This behavior in and of itself should be sufficient to avoid TTS onset. In addition, monitoring and mitigation measures often implemented during seismic surveys are designed to detect marine mammals near the airgun array and avoid exposing them to sound pulses that may cause hearing impairment. For example, it is standard protocol for many seismic operators to ramp up airgun arrays, which should allow animals near the airguns at startup time to move away from the source and thus avoid TTS. If animals do incur TTS, it is a temporary and reversible phenomenon unless exposure exceeds the TTS-onset threshold by an amount sufficient to cause PTS. The following subsections summarize the available data on noise-induced hearing impairment in marine mammals.

Sound Exposure Level (SEL)

Sound exposure level is a measure of sound energy, calculated as 10 times the logarithm of the integral (with respect to duration) of the mean-square sound pressure, referenced to 1 $\mu Pa^2 s$ (Kastak et al. 2005; Southall et al. 2007). It is useful for assessing the cumulative level of exposure to multiple sounds because it allows sounds with different durations and involving multiple exposures to be compared in terms of total energy. This type of comparison assumes that sounds with equivalent total energy will have similar effects on exposed subjects, even if the sounds differ in SPL, duration and/or temporal exposure patterns. Sound exposure level likely over estimates TTS and PTS arising from complex noise exposures because it does not take varying levels and temporal patterns of exposure and recovery into account (Southall et al. 2007). Some support for the use of SEL to evaluate TTS and PTS has been shown for marine mammals (e.g., Finneran et al. 2002a; Finneran et al. 2002b, 2005), and this measure will be referred to in the following sections of this document.

Temporary Threshold Shift

Temporary threshold shift is the mildest form of hearing impairment that can occur during exposure to loud sound (Kryter 1985). It is not considered to represent physical injury, as hearing sensitivity recovers relatively quickly after the sound ends. It is, however, an indicator that physical injury is possible if the animal is exposed to higher levels of sound. The onset of TTS is defined as a temporary elevation of the hearing threshold by at least 6 dB (Schlundt et al. 2000). Several physiological mechanisms are thought to be involved with inducing TTS. These include reduced sensitivity of sensory hair cells in the inner ear, changes in the chemical environment in the sensory cells, residual middle-ear muscular activity, displacement of inner ear membranes, increased blood flow, and post-stimulatory reduction in efferent and sensory neural output (Kryter 1994; Ward 1997).

Very few data are available regarding the sound levels and durations that are necessary to cause TTS in marine mammals. Data are available for only three species of cetaceans and three species of pinnipeds. No data are available for mysticete species. No data are available for any free ranging marine mammals or for exposure to multiple pulses of sound during seismic surveys.

TTS in Odontocetes

Most studies of TTS in odontocetes have focused on non-impulsive sound, and all have been carried out on captive animals. A detailed review of all TTS data available for marine mammals can be found in Southall et al. (2007). The following is a summary of key results.

Finneran et al. (2005) measured TTS in bottlenose dolphins exposed to 3 kHz tones with various durations and SPL levels in a quiet pool. The amount of TTS was positively correlated with the SEL, and statistically significant amounts of TTS were observed for SELs > 195 dB re 1µPa^{2}s. These data agree with those reported by Schlundt et al. (2000) and Nachtigall et al. (2004) and support the use of 195 dB re 1µPa^{2}s as a threshold for TTS onset in dolphins and belugas exposed to mid-frequency sounds. Finneran et al. (2005) also found that each additional dB of SEL produced an additional 0.4 dB of TTS and that for TTS of 3-4 dB, recovery was nearly complete within 10 minutes post-exposure. For larger TTS, longer recovery times were required. The authors caution, however, that interpretation of TTS growth and recovery curves is hampered by the very small amounts of TTS measured relative to the variability of the measurements. They also note that not all exposures above a certain TTS threshold will cause TTS. For example, only 18 percent of exposures to an SEL of 195 dB re 1µPa^{2}s resulted in measurable TTS.

Mooney et al. (2009a) measured TTS in a bottlenose dolphin exposed to octave-band non-impulse noise ranging from 4 to 8 kHz at SPLs of 130-178 dB re 1µPa for 1.88 to 30 min. The results of this study showed a strong positive relationship between SEL and the amount of TTS, however, the relationship was not a simple equal energy relationship. When SEL was kept constant and exposure duration decreased, TTS did not stay constant, as expected by the equal energy rule. The amount and occurrence of TTS decreased as the duration of sound exposure decreased, so relative to longer duration exposures, shorter duration exposures required greater SELs to induce TTS. Recovery time also varied with both SPL and duration of sound exposure and followed a logarithmic function according to the amount of TTS. Similar results were reported by Mooney et al (2009b). The results of this work illustrate the importance of reporting both SPL and duration of sound exposure when evaluating TTS in odontocetes.

The TTS threshold for odontocetes exposed to a single impulse from a watergun appears to be lower than that for exposure to non-impulse sound (Finneran et al. 2002a; Finneran et al. 2002b). An exposure SEL of 186 dB re 1µPa^{2}s resulted in mild TTS in a beluga whale. However, these measurements were made in the presence of band-limited white noise (masking noise), which may have resulted in a lower TTS than would have been observed in the absence of masking noise. Data from terrestrial mammals also show that broadband pulsed sounds with rapid rise times have a greater auditory effect than do non-impulse sounds (Southall et al. 2007). The rms level of an airgun pulse is typically 10-15 dB higher than the SEL for the same pulse when received within a few km of the airguns. A single airgun pulse might therefore need to have a received level of approx 196-201 dB re 1 µPa rms to produce brief, mild TTS. Exposure to several strong seismic pulses, each with a flat-weighted received level near 190 dB rms (175-180 dB sound energy level [SEL]) could result in cumulative exposure of approximately 186 dB SEL and thus slight TTS in a small odontocete.

While the majority of TTS research has been conducted on bottlenose dolphins and beluga whales, one study involved another odontocete species, the harbor porpoise (Lucke et al. 2009). The TTS threshold for this harbor porpoise was lower than that measured for the larger odontocetes. TTS occurred in the harbor porpoise upon exposure to one airgun pulse with a received level of approximately 200 dB re 1 µPa peak-peak or an SEL of 164.3 dB re 1µPa^{2}s.

When estimating the amount of sound energy required for the onset of TTS, it is generally assumed that the effect of a given cumulative SEL from a series of pulses is the same as if that amount of sound energy were received as a single strong sound (Southall et al. 2007). However, some recovery may occur between pulses and it is not currently known how this may affect TTS threshold. In addition, more data are needed in order to determine the received levels at which odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sound with variable received levels. For example, the total energy received by an animal will be a function of received levels of airgun pulses as an airgun array approaches, passes at various distances and moves away (e.g., Erbe and King 2009). Finally, as TTS threshold was lower for the harbor porpoise than for bottlenose dolphins or beluga whales, more data are needed regarding TTS thresholds in other odontocete species.

TTS in Pinnipeds

Temporary threshold shift has been measured for only three pinniped species: harbor seals, California sea lions, and northern elephant seals, and only one study has examined TTS in response to exposure to underwater pulses (Finneran et al. 2003). Of the three species for which data are available, the harbor seal exhibits TTS onset at the lowest exposure levels to non-pulsed sounds. A 25 minute exposure to a 2.5 kHz sound elicited TTS in a harbor seal at an SPL of 152 dB re 1 µPa (SEL 183 dB re 1µPa^{2}s), as compared to 174 dB re 1 µPa (SEL 206 dB re 1µPa^{2}s) for the California sea lion and 172 dB re 1 µPa (SEL 204 dB re 1µPa^{2}s) for the elephant seal (Kastak et al 2005).

The auditory response of pinnipeds to underwater pulsed sounds has been examined in only one study. Finneran et al. (2003) measured TTS onset in two captive California sea lions exposed to single underwater pulses produced by an arc-gap transducer. No measurable TTS was observed following exposures up to a maximum level of 183 dB re 1 µ Pa peak-to-peak (SEL 163 dB re 1µPa^{2}s). Finneran et al. (2003) suggest that the equal energy rule may apply to pinnipeds, however Kastak et al. (2005) found that for harbor seals, California sea lions and elephant seals exposed to prolonged non-impulse noise, higher SELs were required to elicit a given TTS if exposure duration was short than if it was longer. For example, for a non-impulse sound, doubling the exposure duration from 25 to 50 min (a 3 dB increase in SEL) had a greater effect on TTS than an increase of 15 dB (95 vs. 80 dB) in exposure level. These results are similar to those reported by Mooney et al. (2009a, b) for bottlenose dolphins and emphasize the need for taking both SPL and duration into account when evaluating the effect of sound exposure on marine mammal auditory systems.

Permanent Threshold Shift (PTS)

Permanent threshold shift is defined as ‘irreversible elevation of the hearing threshold at a specific frequency’ (Yost 2000). It involves physical damage to the sound receptors in the ear and can be either total or partial deafness or impaired ability to hear sounds in specific frequency ranges (Kryter 1985). Some causes of PTS are severe extensions of effects underlying TTS (e.g. irreparable damage to sensory hair cells). Others involve different mechanisms, for example exceeding the elastic limits of certain tissues and membranes in the middle and inner ears and resultant changes in the chemical composition of inner ear fluids (Ward 1997; Yost 2000). The onset of PTS is determined by pulse duration, peak amplitude, rise time, number of pulses, inter-pulse interval, location, species and health of the receivers ear (Ketten 1994).

The relationships between TTS and PTS thresholds have not been studied in marine mammals and there is currently no evidence that exposure to airgun pulses can cause PTS in any marine mammal, however there has been speculation about that possibility (e.g. Richardson et al. 1995; Gedamke et al. 2008). In terrestrial mammals, prolonged exposure to sounds loud enough to elicit TTS can cause PTS. Similarly, shorter term exposure to sound levels well above the TTS threshold can also cause PTS (Kryter 1985). Terrestrial mammal PTS thresholds for impulse sounds are thought to be at least 6 dB higher than TTS thresholds on a peak-pressure basis (Southall et al. 2007). Also, pulses with rapid rise times can result in PTS even when peak levels are only a few dB higher than the level causing slight TTS.

Southall et al. (2007) used available marine mammal TTS data and precautionary extrapolation procedures based on terrestrial mammal data to estimate exposures that may be associated with PTS onset. For terrestrial mammals, TTS exceeding 40 dB generally requires a longer recovery time than smaller TTS, which suggests a higher probability of irreversible damage (Ward 1970) and possibly different underlying mechanisms (Kryter 1994; Nordman et al. 2000). Based on this, and the similarities in morphology and functional dynamics among mammalian cochleae, Southall et al. (2007) assumed that PTS would be likely if the hearing threshold was increased by more than 40 dB and assumed an increase of 2.3 dB in TTS with each additional dB of sound exposure. This translates to an injury criterion for pulses that is 15 dB above the SEL of exposures causing TTS onset. Finneran et al. (2002a) found TTS onset in belugas exposed to a single pulse of sound at an SEL of 183 dB re 1µPa^2s. Therefore, according to the assumptions above, the PTS threshold would be approximately 198 dB re 1µPa^2s for a single pulse.

There are no data on the sound level of pulses that would cause TTS onset in pinnipeds. Southall et al. (2007) therefore assumed that known pinniped-to-cetacean differences in TTS-onset for non-pulsed sounds also apply to pulse sounds. Harbor seals experience TTS onset at received levels that are 12 dB lower than those required to elicit TTS in beluga whales (Kastak et al. 2005; Finneran 2002a). Therefore, TTS onset in pinnipeds exposed to a single underwater pulse was estimated to occur at an SEL of 171 dB re 1µPa^2s. Adding 15 dB results in a PTS onset of 186 dB re 1µPa^2s for pinnipeds exposed to a single pulse. This is likely to be a precautionary estimate as the harbor seal is the most sensitive pinniped species studied to date and these results are based on measurements taken from a single individual (Kastak et al. 1999, 2005).

It is unlikely that a marine mammal would remain close enough to a large airgun array long enough to incur PTS. Some concern arises for bowriding dolphins, however the auditory effects of seismic pulses are reduced by Llyod’s mirror and surface release effects. In addition, the presence of the ship between the bowriding animals and the airgun array may also reduce received levels (e.g. Gabriele and Kipple 2009). As discussed in the TTS section, the levels of successive pulses received by a marine mammal will increase and then decrease gradually as the seismic vessel approaches, passes and moves away, with periodic decreases also caused when the animal goes to the surface to breath, reducing the probability of the animal being exposed to sound levels large enough to elicit PTS.

9.0 Description of Impact on Subsistence Uses

The anticipated impact of the activity on the availability of the species or stocks of marine mammals for subsistence uses.

The Cook Inlet beluga whale has traditionally been hunted by Alaska Natives for subsistence purposes. For several decades prior to the 1980s, the Native Village of Tyonek residents were the primary subsistence hunters of Cook Inlet beluga whales. During the 1980s and 1990s, Alaska Natives from villages in the western, northwestern, and North Slope regions of Alaska either moved to or visited the south central region and participated in the yearly subsistence harvest (Stanek 1994). From 1994 to 1998, NMFS estimated 65 whales per year (range 21-123) were taken in this harvest, including those successfully taken for food, and those struck and lost. NMFS has concluded that this number is high enough to account for the estimated 14 percent annual decline in population during this time (Hobbs et al. 2008). Actual mortality may have been higher, given the difficulty of estimating the number of whales struck and lost during the hunts. In 1999, a moratorium was enacted (Public Law 106-31) prohibiting the subsistence take of Cook Inlet beluga whales except through a cooperative agreement between NMFS and the affected Alaska Native organizations. Since the Cook Inlet beluga whale harvest was regulated in 1999 requiring cooperative agreements, five beluga whales have been struck and harvested. Those beluga whales were harvested in 2001 (one animal), 2002 (one animal), 2003 (one animal), and 2005 (two animals). The Native Village of Tyonek agreed not to hunt or request a hunt in 2007, when no co-management agreement was to be signed (NMFS 2008a).

The 2008 Cook Inlet Beluga Whale Subsistence Harvest Final Supplemental Environmental Impact Statement (NMFS 2008a) authorizes how many beluga whales can be taken during a five-year interval based on the 5-year population estimates and 10-year measure of the population growth rate. Based on the 2008 - 2012 five-year abundance estimates, no hunt occurred between 2008 and 2012 (NMFS 2008a). The Cook Inlet Marine Mammal Council, which managed the Alaska Native Subsistence fishery with NMFS, was disbanded by a unanimous vote of the Tribes' representatives on June 20, 2012. At this time, no harvest is expected in the near future.

Residents of the Native Village of Tyonek are the primary subsistence users in Knik Arm area. The project should not have any effect because beluga harvest is not foreseen to take place and the area is not an important native subsistence site for other subsistence species of marine mammals.

Data on the harvest of other marine mammals in Cook Inlet are lacking. Some data are available on the subsistence harvest of harbor porpoises, and killer whales in Alaska in the marine mammal stock assessments. However, these numbers are for the Gulf of Alaska including Cook Inlet, and they are not indicative of the harvest in Cook Inlet. Because the relatively small proportion of marine mammals utilizing Cook Inlet, the number harvested is expected to be extremely low. Since the proposed seismic program would result in only temporary disturbances, this program is not expected to impact the availability of these other species for subsistence uses.

Some detailed information on the subsistence harvest of harbor seals is available from past studies conducted by ADF&G (Wolfe et al. 2009). In 2008, 33 harbor seals were taken for harvest in the Upper Kenai-Cook Inlet area. In the same study, reports from hunters stated that harbor seal populations in the area were perceived to be increasing (28.6 percent of hunters) or remaining stable (71.4 percent of hunters). The specific hunting regions identified were Anchorage, Homer, Kenai, and Tyonek, and hunting generally peaks in March, September, and November (Wolfe et al. 2009). The timing and location of subsistence harvest of Cook Inlet harbor seals may coincide with Apache's project, but because this subsistence hunt is conducted opportunistically and at such a low level (NMFS 2013c), Apache's program is not expected to have an impact on the subsistence use of harbor seals.

10.0 Description of Impact on Marine Mammal Habitat

The anticipated impact of the activity upon the habitat of the marine mammal populations, and the likelihood of restoration of the affected habitat.

Fish are the primary prey species for marine mammals in upper Cook Inlet. Beluga whales feed on a variety of fish, shrimp, squid, and octopus (Burns and Seaman 1986). Common prey species in Knik Arm include salmon, eulachon and cod. Harbor seals feed on fish such as pollock, cod, capelin, eulachon, Pacific herring, and salmon as well as a variety of benthic species, including crabs, shrimp, and cephalopods. Harbor seals are also opportunistic feeders with their diet varying with season and location. The preferred diet of the harbor seal in the Gulf of Alaska consists of pollock, octopus, capelin, eulachon, and Pacific herring (Calkins 1989). Other prey species include cod, flat fishes, shrimp, salmon, and squid (Hoover 1988). Harbor porpoises feed primarily on Pacific herring, cod, whiting (hake), pollock, squid, and octopus (Leatherwood et al. 1982). In the upper Cook Inlet area, harbor porpoise feed on squid and a variety of small schooling fish, which would likely include Pacific herring and eulachon (Bowen and Siniff 1999; NMFS unpublished data). Killer whales feed on either fish or other marine mammals depending on genetic type (resident versus transient respectively). The few killer whales observed in Upper Cook Inlet are typically the transient type (Shelden et al. 2003) and feed on beluga whales and other marine mammals, such as harbor seal and harbor porpoise.

While there may be few definitive studies on fish use of the nearshore shallow coastal areas in the upper inlet, use of this type of habitat elsewhere by salmon and other species in Cook Inlet is supported in literature (NMFS 2008b). In general, fish perceive underwater sounds in the frequency range of 50 to 2,000 Hz, with peak sensitivities below 800 Hz (Popper and Carlson 1998; Department of the Navy 2001). However, fish are sensitive to underwater impulsive sounds due to swimbladder resonance. As the pressure wave passes through a fish, the swimbladder is rapidly squeezed as the high pressure wave, and then the under pressure component of the wave, passes through the fish. The swimbladder may repeatedly expand and contract at the high sound pressure levels (SPL), creating pressure on the internal organs surrounding the swimbladder.

Permanent injury to fish from acoustic emissions has been shown for high-intensity sounds of several hours long. In a review on the effects of low-frequency noise to fish, a threshold of 180 dB peak sound level was used to define the potential injury to fish. Sound pressure levels greater than an average of 150 dB rms are expected to cause temporary behavioral changes such as a startle response or behaviors associated with stress. Although these SPLs are not expected to cause direct injury to a fish, they may decrease the ability of a fish to avoid predators.

Carlson (1994), in a review of 40 years of studies concerning the use of underwater sound to deter salmonids from hazardous areas at hydroelectric dams and other facilities, concluded that salmonids were able to respond to low-frequency sound and to react to sound sources within a few feet of the source. He speculated that the reason that underwater sound had no effect on salmonids at distances greater than a few feet is because they react to water particle motion/acceleration, not sound pressures. Detectable particle motion is produced within very short distances of a sound source, although sound pressure waves travel farther.

Hastings and Popper (2005) reviewed all pertinent peer-reviewed and unpublished papers on noise exposure of fish through early 2005. They proposed the use of SEL to replace peak SPL in pile driving criteria. This report identified interim thresholds based on SEL or sound energy.

The interim thresholds for injury were based on exposure to a single pile driving pulse. The report also indicates that there was insufficient evidence to make any findings regarding behavioral effects associated with these types of sounds. Interim thresholds were identified for pile driving consisting of a single-strike peak sound pressure and a single strike SEL for onset of physical injury. A peak pressure criterion was retained to function in concert with the SEL value for protecting fishes from potentially damaging aspects of acoustic impact stimuli. The available scientific evidence suggested that a single-strike peak pressure of 208 dB and a single strike SEL of 187 dB were appropriate thresholds for the onset of physical injury to fishes.

Following the Hasting and Popper (2005) paper, NMFS developed their version of the dual criteria that included the single strike peak pressure threshold of 208 dB, but addressed the accumulation of multiple strikes through accumulation of sound energy by setting a criterion of 187 dB SEL. The accumulated SEL is calculated using an equal energy hypothesis that combines the SEL of a single strike to 10 times the 10-based logarithm of the number of pile strikes.

Only a small fraction of the potentially available habitat in Cook Inlet would be impacted by noise from the Cook Inlet Seismic Program at any given time during the seismic survey. Furthermore, the constant movement of the seismic vessel and the short duration of actual seismic activity would result in short-term, temporary, and very localized acoustic impacts on fish and other prey species. Thus, the seismic program is not expected to have any effects on habitat or prey that could cause permanent or long-term consequences for marine mammals.

11.0 Description of Impact from Loss or Modification to Habitat

The anticipated impact of the loss or modification of habitat on the marine mammal populations involved.

The proposed Cook Inlet Seismic Program will not result in any permanent impact on habitats used by marine mammals, or to the food sources they utilize. Direct habitat impacts such as physical destruction or alteration of habitat will not occur from the seismic program. Indirect impacts may be caused by ensonification of habitat from seismic operations noises, which will be very localized and short term. Ensonification from seismic operations should have no more than a negligible effect on marine mammal habitat because:

- No studies have demonstrated that seismic noise affects the life stages, condition, or amount of food resources (fish, invertebrates, eggs) comprising habitats used by marine mammals, except when exposed to sound levels within a few meters of the seismic source or in a few very isolated cases. Where fish or invertebrates did respond to seismic noise, the effects were temporary and of short duration. Consequently, disturbance to fish species would be short-term and fish would return to their pre-disturbance behavior once the seismic activity ceases. Thus, the proposed survey would have little, if any, impact on marine mammals ability to feed in areas where seismic work is planned.
- The seismic area covers a small percentage of the potentially available habitat used by marine mammals in Cook Inlet allowing beluga whales and other marine mammals to move away from any seismic program sounds.

Thus, the proposed activity is not expected to have any habitat-related effects that could cause significant or long-term consequences for individual marine mammals or their populations, since operations will be limited in duration, location, timing, and intensity.

12.0 Measures to Reduce Impacts to Marine Mammals

The availability and feasibility [economic and technological] of equipment, methods, and manner of conducting such activity or other means of effecting the least practicable adverse impact upon the affected species or stocks, their habitat, and on their availability for subsistence uses, paying particular attention to rookeries, mating grounds, and areas of similar significance.

The primary marine mammal species with potential to be exposed to seismic sounds during the seismic program will be beluga whales, harbor seals, and harbor porpoises. Killer whales and Steller sea lions have been sighted in upper Cook Inlet, but their occurrence is considered rare. There are no known rookeries, mating grounds or areas of similar significance in the project area. The following section describes the proposed measures to minimize incidental takes by harassment of all marine mammals.

12.1 Vessel-Based Monitoring

Vessel-based visual PSOs will monitor for marine mammals from vessel platforms during all daytime airgun operations. These observations will provide the real-time data needed to implement some of the key mitigation measures. When marine mammals are observed within, or about to enter the Level A exclusion zone (180 dB for cetaceans or 190 dB for pinnipeds; hereafter referred to as exclusion zones) or Level B disturbance zone (160 dB; hereafter referred to as disturbance zone) appropriate mitigation measures will be implemented to prevent/minimize potential behavioral or physical effects. Mitigation measures will be communicated by the PSO on the source vessel to the airgun operators and vessel captain/crew.

During daytime operations, vessel-based observers will watch for marine mammals at the project location during all periods of seismic operations and for a minimum of 30 minutes prior to the planned start of airgun operations after a shut down of 10 minutes or more. PSOs will also observe opportunistically during daylight hours when no seismic activity is taking place.

Apache proposes to conduct both daytime and nighttime seismic operations. Hours surveyed during periods of low visibility will depend on the time of year and tidal cycles. Apache only conducts their seismic acquisitions during periods of slack tide, which in Cook Inlet occur four times over a 24-hour period and last 2-3 hours each, totaling 8-12 hours of potential survey time per 24-hour period. Nighttime operations can be initiated only if a mitigation gun has been continuously operational from the time that the PSO monitoring ended. Seismic activity will not commence after a shut down during nighttime operations. PSOs typically will not monitor during seismic operations at night. Vessel captain and crew will watch for marine mammals (insofar as practical at night) and will call for the airgun(s) to be powered down (and possibly shut down) if marine mammals are observed in or about to enter the 160 dB disturbance zone. After a shut down of seismic operations during night operations, seismic activity will be suspended until the following day and when the full 160 dB disturbance zone is visible for at least 30 minutes.

12.2 Proposed Exclusion Zone

In order to avoid any takes by injury (Level A), Apache proposes to power down (or possibly shut down) airguns or positioning pingers in the event any marine mammal approaches or enters the applicable 180 or 190 dB exclusion zone. NMFS requires monitoring of the 160 dB disturbance zone specifically for all belugas and groups of five or more harbor porpoises and killer whales. When these marine mammals are observed within, or about to enter the 160 dB disturbance zone, airgun operations will be powered down (or shut down if necessary) immediately. As discussed in detail in Appendix C, to determine the distances (or radii) of the 160, 180 and 190 dB isopleths, were modeled for the first Apache IHA application. In field SSV of the received levels for the 440 and 2,400 in^3 airgun configurations were conducted in 2012 to verify the distances to the 160, 180 and 190 dB isopleths. The results of which are provided in Appendices B, C and D. The modeled 160 dB disturbance zones were used to estimate probability of occurrence for marine mammals in this document, but the measured 160, 180 and 190 dB isopleths (based on the SSV) will be used for monitoring during the seismic survey. These distances are provided in Table 9.

Table 9. Summary of Measured Distance to NMFS Sound Level Thresholds

Source	190 dB	180 dB	160 dB
	(m)	(m)	(m)
Pinger	1	3	25
10 in^3 air gun	10	10	280
400 in^3 air gun	100	310	2,500
2,400 in^3 air gun (nearshore)	380	1,400	9,500
2,400 in^3 air gun (offshore)	290	910	8,700

Apache proposes to monitor these zones for marine mammals before, during and after the operation of the offshore airguns and pingers. Monitoring will be conducted using qualified PSOs on three vessels, as discussed in Section 14.

12.3 Power-Down Procedure

A power down procedure involves reducing the number of airguns, typically to the 10 in^3 mitigation airgun to significantly reduce the size of the exclusion and disturbance zones (Table 9). If a marine mammal (excluding beluga whales) is already detected approaching or within the 180 or 190 dB exclusion zone the airguns will be powered down. If a beluga whale is observed approaching or within the 180 dB exclusion zone, the airguns will be shut down immediately (see below). If a beluga whales and/or group of five or more harbor porpoise or killer whales are detected approaching or within the 160 dB disturbance zone, the airguns may be powered down before the animal is within the 160 dB disturbance zone, as an alternative to a complete shut down.

Following a power down, airgun activity will not resume until the marine mammal has cleared the applicable exlusion or disturbance zone. The animal will be considered to have cleared the exclusion / disturbance zone if it:

- is visually observed to have left the zone,
- has not been seen within the zone for 15 minutes in the case of pinnipeds and small odontocetes, including Steller sea lions, harbor seals, and harbor porpoise, or
- has not been seen within the zone for 30 minutes in the case of species with longer dive durations (beluga whales and killer whales).

12.4 Shut-Down Procedure

A shut-down procedure involves the cessation of all airgun activity. The shut-down procedure will be implemented immediately, generally within several seconds of the determination that a marine mammal is either in or about to enter the appropriate exclusion or disturbance zone of the mitigation airgun.

Following a shut down, airgun activity will not resume until the marine mammal has cleared the applicable exclusion or disturbance zone. The animal will be considered to have cleared the exclusion/disturbance zone if it:

- is visually observed to have left the zone,
- has not been seen within the zone for 15 minutes in the case of pinnipeds and small odontocetes, including Steller sea lions, harbor seals, and harbor porpoise, or
- has not been seen within the zone for 30 minutes in the case of species with longer dive durations (beluga whales and killer whales).

After a shut down during night operations, seismic survey activities will be suspended until daylight, when the 160 dB disturbance zone is visible for at least 30 minutes.

12.5 Ramp-Up Procedure

A ramp-up procedure gradually increases airgun volume at a specified rate. Apache will use the ramp-up procedure at the start of airgun operations, after a power down, shut down or any period of 10 minutes or more without airgun operations. NMFS normally requires ramp-up rates of no more than 6 dB per 5-minute period. Ramp-up will begin with the smallest gun in the array. During the ramp-up, the 160 dB disturbance zone for the full airgun array will be maintained.

If the complete 160 dB disturbance zone has not been visible for at least 30 minutes prior to the start of operations, ramp-up will not commence unless the mitigation gun has been continuously operating during the interruption of seismic survey operations. This means that it will not be permissible to ramp up from a complete shut down in thick fog or at other times when the outer part of the exclusion zone is not visible. Ramp up of the airguns will not be initiated if a marine mammal is sighted within or near the 160 dB disturbance zone at any time.

During ramp-up, if a marine mammal is observed approaching or within a 160 dB disturbance zone, power-down or shut-down procedures will be implemented as necessary.

12.6 Speed or Course Alteration

If a marine mammal is detected approaching the applicable exclusion or disturbance zone, the vessel may adjust its speed and/or course, when practical and safe to do so, and when it will not negatively impact marine mammals. These actions can be used in coordination with a power-down or shut-down procedure, if practical.

12.7 Implementation of Marine Mammal Mitigation

When a marine mammal is sighted within or approaching the applicable exclusion or disturbance zone and a power down does not keep it out of the zone of the mitigation airgun, PSOs will radio in a shut down immediately by calling "Shut down, shut down, shut down." Personnel on the source vessels will respond that they are shut down. PSOs on the source vessels will record shut down request time and implementation time (both to the second). During a shut down, resulting from a marine mammal encounter, the PSO will use specialized marine mammal observational software to estimate the distance of the marine mammal to the source vessel(s). In the event that the marine mammal is determined to be outside the applicable exclusion or disturbance zone during the 10 minute shut-down window, the seismic operations will be restarted at full volume. In the event that the marine mammal is determined to be within the applicable exclusion or disturbance zone, PSOs will maintain the shut down for the specified duration (15 minutes for pinnipeds and harbor porpoise and 30 minutes for large odontocetes). If the shut down of seismic operations is greater than the allowed 10 minute window, a full ramp up will be implemented following the defined ramp up procedure.

13.0 Measures to Reduce Impacts to Subsistence Users

Where the proposed activity would take place in or near a Traditional Arctic Subsistence Hunting area and/or may affect the availability of a species or stock of marine mammal for Arctic subsistence uses, the applicant must submit either a plan of cooperation or information that identifies what measures have been taken and/or will be taken to minimize any adverse effects on the availability of marine mammals for subsistence uses.

Since November 2010, Apache has met and continues to meet with many of the villages and traditional councils throughout the Cook Inlet region. During these meetings, no concerns have been raised regarding potential conflict with subsistence harvest[1].

Additionally, Apache met with the Cook Inlet Marine Mammal Council (CIMMC) to describe the Project activities and discuss subsistence concerns. The meeting provided information on the time, location, and features of the proposed program, opportunities for involvement by local people, potential impacts to marine mammals, and mitigation measures to avoid impacts. Discussions regarding marine seismic operations continued with the CIMMC until its disbandment.

In 2014, Apache held meetings or discussions regarding project activities with the following entities: Native Village of Tyonek, Tyonek Native Corporation, Cook Inlet Region, Inc., Ninilchik Native Association, Ninilchik Tribal Council, Salamatof Native Association, Cook Inlet Keeper, Alaska Salmon Alliance, Upper Cook Inlet Drift Association, and the Kenai Peninsula Fisherman's Association. Further, Apache has placed posters in local businesses, offices, and stores in nearby communities and published newspaper ads in the Peninsula Clarion.

The features of the program should prevent any adverse effects on the availability of marine mammals for subsistence.

- In-water seismic activities will follow mitigation and monitoring procedures as described in Sections 12 and 14 of this application to minimize effects on the behavior of marine mammals and; therefore, opportunities for harvest by Alaska Native communities.
- Regional subsistence representatives may support recording marine mammal observations along with marine mammal biologists during the monitoring program and be provided annual reports.
- The size of the affected area, mitigation measures, and input from the CIMMC should result in the program having no effect on the availability of marine mammals for subsistence uses.

[1] Past meetings have been held with Alexander Creek, Knikatnu, Native Village of Tyonek, Salamatof, Tyonek Native Corporation, Ninilchik Traditional Council, Ninilchik Native Association, Village of Eklutna, Kenaitze Indian Tribe, and Cook Inlet Region, Inc.

14.0 Monitoring and Reporting

The suggested means of accomplishing the necessary monitoring and reporting that will result in increased knowledge of the species, the level of taking or impacts on populations of marine mammals that are expected to be present while conducting activities and suggested means of minimizing burdens by coordinating such reporting requirements with other schemes already applicable to persons conducting such activity. Monitoring plans should include a description of the survey techniques that would be used to determine the movement and activity of marine mammals near the activity site(s) including migration and other habitat uses, such as feeding. Guidelines for developing a site-specific monitoring plan may be obtained by writing to the Director, Office of Protected Resources.

14.1 Monitoring

Apache's proposed Monitoring Plan is described below. Apache understands that this Monitoring Plan will be subject to review by NMFS and others, and that refinements may be required. Specific monitoring programs (e.g. aerial monitoring) may be proposed in annual LOA applications.

14.1.1 Visual Boat-Based Monitoring

Three vessels will employ PSOs to identify marine mammals during all daytime hours of airgun operations: the two source vessels (*M/V Peregrine Falcon* and/or *M/V Arctic Wolf* or similar) and one support vessel (*M/V Dreamcatcher* or similar). Two PSOs will be on the source vessels and two PSOs on the support vessel in order to better observe the safety, power-down, and shut-down areas. On each vessel, one PSO will be on watch for four hours before being relieved by the second PSO for four hours. Therefore, between all three vessels, six PSOs will be on board with three on watch at any given time. When marine mammals are about to enter or are sighted within designated exclusion/disturbance zones, airgun or pinger operations will be powered down (when applicable) or shut down immediately. The vessel-based observers will watch for marine mammals at the seismic operation during all periods of source effort and for a minimum of 30 minutes prior to the planned start of airgun or pinger operations after an extended shut down. Apache personnel will also watch for marine mammals (insofar as practical) and alert the observers in the event of a sighting. Apache personnel will be responsible for the implementation of mitigation measures only when a PSO is not on duty (e.g., nighttime operations).

Seismic operations will not be initiated or continue when adequate observation of the designated exclusion zone is not possible due to environmental conditions such as high sea state, fog, ice and low light. Termination of seismic operations will be at the discretion of the lead PSO based on continual observation of environmental conditions and communication with other PSOs.

With NMFS consultation, PSOs will be hired by Apache or its designee. Apache will provide the curriculum vitae and references for all PSOs. PSOs will follow a schedule so observers will monitor marine mammals near the seismic vessel during all ongoing operations and air-gun ramp ups. PSOs will normally be on duty in shifts no longer than four hours with two hour minimum breaks to avoid observation fatigue. The vessel crew will also be instructed to assist in detecting marine mammals and implementing mitigation requirements (if practical). Before the start of the seismic survey the crew will be given additional instruction on how to do so.

The source and support vessels are suitable platform for marine mammal observations. When stationed on the third deck and/or flying bridge, the observer will have an unobstructed view around the entire vessel. If surveying from the bridge, the observer's eye level will be about 6 m (20 ft) above sea level. During operations, the PSO(s) will scan the area around the vessel systematically with reticule binoculars (e.g., 7×50 or equivalent) and with the naked eye. Laser range finders (Leica LRF 1200 laser rangefinder or equivalent) will be available to assist with distance estimation. They are useful in training observers to estimate distances visually, but are generally not useful in measuring distances to animals directly.

PSOs observing from the mitigation vessel will be equipped with big eye (20x100) binoculars.

All observations and/or mitigation measures will be recorded in a standardized format. Data will be entered into a custom database using a notebook computer. The accuracy of the data entry will be verified by computerized validity data checks as the data are entered and by subsequent manual checking of the database. These procedures will allow initial summaries of data to be prepared during and shortly after the field program, and will facilitate transfer of the data to statistical, graphical, or other programs for further processing and archiving.

Results from the vessel-based visual observations will provide:

- The basis for real-time mitigation (airgun shut down, power down, and ramp up).
- Data on the occurrence, distribution, and activities of marine mammals in the area where the seismic study is conducted.
- Information to compare the distance and distribution of marine mammals relative to the source vessel at times with and without seismic activity.
- Data on the behavior and movement patterns of marine mammals seen at times with and without seismic activity.

14.1.2 Visual Shore-Based Monitoring

In addition to the vessel-based PSOs, Apache proposes to utilize a single shore-based station when possible. Two PSOs will observe from one or more shore-based platforms locations based on the best combination of the following: view of the seismic vessels, proximity to shore, platform height, access, and safety. Shore-based PSOs will observe during all daylight periods during seismic and pinger operations and ramp-ups, and during non-seismic and non-pinger operation periods to the maximum extent practicable, weather and safety permitting.

The shore-based station will follow all safety procedures, including bear safety. The shore-based location will need to have sufficient height to observe marine mammals; the PSO would be outfitted with big-eye (20x100) binoculars. The PSO would scan the area prior to, during, and after the airgun operations. One PSO would observe through Big Eyes and the second would observe with the naked eye. The PSO would be in contact with the other PSOs on the vessels, as well as the source vessel operator via radio to be able to communicate the sighting of a marine mammal approaching or sighted within the project area.

14.2 Reporting

Immediate reports will be submitted to NMFS if 25 belugas are detected in the 160 dB exclusion zone to evaluate and make necessary adjustments to monitoring and mitigation. If the number of detected takes meets or exceeds the amount authorized for any marine mammal species, Apache will immediately cease survey operations involving the use of active sound sources (e.g., air guns and pingers) and notify NMFS.

Weekly reports will be submitted to NMFS no later than the close of business (Alaska time) each Thursday during the weeks when in-water seismic activities take place. The field reports will summarize species detected (number, location, distance from seismic vessel, behavior), in-water activity occurring at the time of the sighting (discharge volume of array at time of sighting, seismic activity at time of sighting, visual plots of sightings, and number of power-downs and shut downs), behavioral reactions to in-water activities, and the number of marine mammals taken.

Monthly reports will be submitted to NMFS for all months during which in-water seismic activities take place. The monthly report will contain and summarize the following information:

1. Dates, times, locations, heading, speed, weather, sea conditions (including Beaufort sea state and wind force), and associated activities during all seismic operations and marine mammal sightings;
2. Species, number, location, distance from the seismic vessel, and behavior of any marine mammals, as well as associated seismic activity (discharge volume of array at time of sighting, seismic activity at time of sighting, visual plots of sightings, and number of power downs and shut downs), observed throughout all monitoring activities.
3. An estimate of the number (by species) of: (A) pinnipeds that have been exposed to the seismic activity (based on visual observation) at received levels greater than or equal to 160 dB re 1 µPa (rms) and/or 190 dB re 1 µPa (rms) with a discussion of any specific behaviors those individuals exhibited; and (B) cetaceans that have been exposed to the seismic activity (based on visual observation) at received levels greater than or equal to 160 dB re 1 µPa (rms) and/or 180 dB re 1 µPa (rms) with a discussion of any specific behaviors those individuals exhibited.
4. A description of the implementation and effectiveness of the: (A) terms and conditions of the BiOp's Incidental Take Statement (ITS); and (B) mitigation measures of the IHA. For the BiOp, the report shall confirm the implementation of each Term and Condition, as well as any conservation recommendations, and describe their effectiveness, for minimizing the adverse effects of the action on ESA-listed marine mammals.

An annual report will be submitted to NMFS within 90 days after the end of every operating season. The report will summarize all activities and monitoring results conducted during in-water seismic surveys. The Technical Report will include the following:

1. Summaries of monitoring effort (e.g., total hours, total distances, and marine mammal distribution through the study period, accounting for sea state and other factors affecting visibility and detectability of marine mammals);
2. Analyses of the effects of various factors influencing detectability of marine mammals (e.g., sea state, number of observers, and fog/glare);
3. Species composition, occurrence, and distribution of marine mammal sightings, including date, water depth, numbers, age/size/gender categories (if determinable), group sizes, and ice cover;
4. Analyses of the effects of survey operations;
    - sighting rates of marine mammals during periods with and without seismic survey activities (and other variables that could affect detectability), such as:
    - initial sighting distances versus survey activity state;
    - closest point of approach versus survey activity state;
    - observed behaviors and types of movements versus survey activity state;
    - numbers of sightings/individuals seen versus survey activity state;
    - distribution around the source vessels versus survey activity state; and
    - estimates of take by Level B harassment based on presence in the 160 dB disturbance zone.

15.0 Research Coordination

Suggested means of learning of, encouraging, and coordinating research opportunities, plans, and activities relating to reducing such incidental taking and evaluating its effects.

Open-water seismic operations have been conducted in Alaska waters for over 25 years and, during this time, these operations have had no noticeable adverse impacts on the marine mammal populations or their availability for subsistence uses. This includes seismic operations involving airgun arrays more powerful and extensive then the proposed Cook Inlet Seismic Program. Over the time period these larger airgun arrays have been used in the Chukchi and Beaufort seas, bowheads, gray whales, and other species have increased to where they are approaching or at carrying capacity of the habitat. Furthermore, the subsistence harvest of bowhead whales has been very consistent over the last 10 years among the whaling villages suggesting no decrease in their availability for harvest. While studies of seismic surveys on marine mammals have not been conducted in Cook Inlet, those referred above for the Alaska Arctic suggest the nearshore location, site characteristic, short time frame, and limited number and length of time of active seismic operations each day of the proposed Cook Inlet Seismic Program should have no impact on the marine mammal populations.

To further ensure that there will be no adverse effects resulting from the planned seismic operations, Apache will continue to cooperate with NMFS, the Bureau of Ocean Energy Management, other appropriate federal agencies, the State of Alaska, Cook Inlet tribal entities including but not limited to the Native Village of Tyonek and Kenaitze Indian Tribe, affected communities, and other monitoring programs to coordinate research opportunities and assess all measures than can be taken to eliminate or minimize any impacts from their program.

16.0 References

AEA. 2013. Susitna-Wantana Hydroelectric Project. Fish and Aquatic Resources Technical Work Group Meeting. 4th Quarter 2013. December 4, 2013. http://www.susitna-watanahydro.org/wp-content/uploads/2013/11/FishandAquaticsDecTWG.pdf

Allen, B.M. and R.P. Angliss. 2010. Alaska Marine Mammal Stock Assessments, 2009. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-AFSC-206, 287 p.

Allen, B.M. and R.P. Angliss. 2013. Alaska Marine Mammal Stock Assessments, 2012. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-AFSC-245, 282 p.

Angliss, R.P. and R.B. Outlaw. 2005. Alaska Marine Mammal Stock Assessments, 2004. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-AFSC-161, 250 p.

Angliss, R.P., and R.B. Outlaw. 2008. Alaska Marine Mammal Stock Assessments, 2007. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-AFSC-180, 252 p.

Au, W. W. L., D. A. Carder, P. R.H., and B. L. Scronce. 1985. Demonstration of adaptation in beluga whale (*Delphinapterus leucas*) echolocation signals. Journal of the Acoustical Society of America. 77(2):726-730.

Awbrey, F.T., J.A. Thomas, and R.A. Kasetelein. 1988. Low frequency underwater hearing sensitivity in belugas, *Delphinapterus leucas*. Journal of the Acoustical Society of America 84:2273-2275.

Blackwell, S.B. and C.R. Greene Jr. 2002. Acoustic measurements in Cook Inlet, Alaska during August 2001. Greeneridge Report 271-2. Report from Greeneridge Sciences, Inc., Santa Barbara for National Marine Fisheries Service, Anchorage, Alaska. 43 p.

Boveng, P., J. London, J. Ver Hoef, and R. Montgomery. 2007. Strong Seasonal Dynamics of Harbor Seals in Cook Inlet, Alaska, 2003-2006. Alaska Fisheries Science Center, National Marine Mammal Laboratory. Scientific Poster accessed 17 September, 2013 at http://dec.alaska.gov/spar/perp/response/sum_fy09/090324201/090324201_Boveng%20poster%20full%20size_NMFS.pdf.

Bowen, W. D. and Siniff, D. B. 1999. Distribution, population biology, and feeding ecology of marine mammals. Reynolds, J. E. III and Rommel, S. A. [eds.] In Biology of Marine Mammals. pp. 423-484. Washington, D.C., Smithsonian Press.

Brueggeman, J.J., M. Smultea, K. Lomac-MacNair, D.J. Blatchford, and R. Dimmick. 2007a. 2007 fall marine mammal monitoring program for the Union Oil Company of California Granite Point seismic operations in Cook Inlet Alaska: 90-day report. Canyon Creek Consulting. Prepared for Union Oil Company of California. 34 pp.

Brueggeman, J.J., M. Smultea, H. Goldstein, S. McFarland, and D.J. Blatchford. 2007b. 2007 spring marine mammal monitoring program for the ConocoPhillips Beluga River seismic operations in Cook Inlet Alaska: 90-day report. Canyon Creek Consulting. Prepared for ConocoPhillips Alaska, Inc. 38 pp.

Brueggeman, J.J., M. Smultea, K. Lomac-MacNair, and D.J. Blatchford. 2008. 2007 fall marine mammal monitoring program for the Marathon Oil Company North Ninilchik seismic operations in Cook Inlet Alaska: 90-day Report. Prepared for Marathon Oil Company. 18 pp.

Burns, J.J., and G.A. Seaman. 1986. Investigations of beluga whales in coastal waters of western and northern Alaska. II. Biology and ecology. U.S. Department of Commerce, NOAA, OCSEAP Final Report 56 (1988): 221-357.

Calkins, D.G. 1989. Status of beluga whales in Cook Inlet. In: Jarvela LE, Thorsteinson LK (eds) Gulf of Alaska, Cook Inlet, and North Aleutian Basin information update meeting. Anchorage, Alaska, Feb. 7–8, 1989, USDOC, NOAA, OCSEAP, Anchorage, Alaska, p 109–112.

Carlson, T.J. 1994. Use of Sound for Fish Protection at Power Production Facilities: A Historical Perspective of the State of the Art. Phase I Final Report: Evaluation of the Use of Sound to Modify the Behavior of Fish. Report No. DOE/BP-62611-4. Prepared for Waterfront Department of Energy; Bonneville Power Administration; Environment, Fish, and Wildlife. November.

Carretta, J.V., E. Oleson, D.W. Weller, A.R. Land, K.A. Forney, J. Baker, B. Hanson, K. Martien, M.M. Muto, T. Orr, H. Huber, M.S. Lowry, J. Barlow, D. Lynch, L. Carswell, R.L. Brownell Jr., and D.K Mattila. 2014. U.S. Pacific Marine Mammal Stock Assessments (DRAFT): 2013. NOAA-TM-NMFS-SWFSC-XXX. U.S. Department of Commerce, Southwest Fisheries Science Center. Accessed June 2014. Available at http://www.nmfs.noaa.gov/pr/sars/pdf/po2013_draft.pdf.

Cornick, L.A. and L.S. Kendall. 2008a. Distribution, habitat use, and behavior of Cook Inlet beluga whales in Knik Arm at the Port of Anchorage Marine Terminal Redevelopment Project. Final Annual Report for 2007. Alaska Pacific University. Prepared for Integrated Concepts & Research Corporation, Anchorage, AK.

Cornick, L.A. and L.S. Kendall. 2008b. End of construction season 2008 marine mammal monitoring report: construction and scientific marine mammal monitoring associated with the Port of Anchorage Marine Terminal Redevelopment Project. May-November 2009. Alaska Pacific University. Prepared for Integrated Concepts & Research Corporation, Anchorage, AK.

Cornick, L.A., L.S. Kendall, and L. Pinney. 2010. Distribution, habitat use, and behavior of Cook Inlet beluga whales in Knik Arm at the Port of Anchorage Marine Terminal Redevelopment Project. Final Annual Report for 2007. Alaska Pacific University. Prepared for Integrated Concepts & Research Corporation, Anchorage, AK.

Crane, N.L. and K. Lashkari. 1996. Sound production of gray whales, *Eschrichtius robustus*, along their migration route: a new approach to signal analysis. J. Acoust. Soc. Am. 100(3): 1878-86.

Dahlheim, M., A. York, R. Towell, J. Waite, and J. Breiwick. 2000. Harbor porpoise (*Phocoena phocoena*) abundance in Alaska: Bristol Bay to Southeast Alaska, 1991-1993. Marine Mammal Science 16:28-45.

Department of the Navy. 2001. Final Overseas Environmental Impact Statement and Environmental Impact Statement for Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) Sonar. January.

Di Iorio, L. and C.W. Clark. 2010. Exposure to seismic survey alters blue whale acoustic communication. Biology Letters (6):51-54.

Engel, M.H., M.C.C. Marcondes, C.A. Martines, FO Luna, R.P. Lima and A.Campos. 2004. Are seismic surveys responsible for cetacean strandings? An unusual mortality of adult humpback whales in Abrolhos Bank, Northeastern coast of Brazil. Paper SC/56/E28 presented to IWC Scientific Committee of the 56st International Whaling Commission.

Erbe, C. and A.R. King. 2009. Modeling cumulative sound exposure around marine seismic surveys. Journal of the Acoustical Society of America 125(4):2443-2451.

Fernández, A., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, E. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham and P.D. Jepson. 2004. Pathology: whales, sonar and decompression sickness (reply). Nature 428(6984, 15 Apr.). doi: 10.1038/nature02528a.

Finneran, J. J., Schlundt, C. E., Carder, D. A., Clark, J. A., Young, J. A., Gaspin, J. B., and Ridgway, S. H. 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and a beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. Journal of the Acoustical Society of America 108:417 431.

Finneran, J.J., C.E. Schlundt, R. Dear, D.A. Carder, and S.H. Ridgway. 2002a. Temporary shift in masked hearing thresholds (MTTS) in odontocetes after exposure to single underwater impulses from a seismic watergun. Journal of the Acoustical Society of America 111:2929-2940.

Finneran, J.J., D.A. Carder, and S.H. Ridgeway. 2002b. Low frequency acoustic pressure, velocity, and intensity thresholds in a bottlenose dolphin (*Tursiops truncatus*) and white whale (*Delphinapterus leucas*). Journal of the Acoustical Society of America 111:447-456.

Finneran, J.J., R. Dear, D.A. Carder, and S.H. Ridgway. 2003. Auditory and behavioral responses of California sea lions (*Zalophus californianus*) to single underwater impulses from an arc-gap transducer. Journal of the Acoustical Society of America 114(3):1667-1677.

Finneran, J.J., D.A. Carder, C.E. Schlundt, and S.H. Ridgway. 2005. Temporary threshold shift (TTS) in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. Journal of the Acoustical Society of America 118:2696-2705.

Funk, D.W., R.J. Rodrigues, and M.T. Williams (eds.). 2005. Baseline studies of beluga whale habitat use in Knik Arm, Upper Cook Inlet, Alaska, July 2004-July 2005. Report from LGL Alaska Research Associates, Inc., Anchorage, Alaska, in association with HDR Alaska, Inc., Anchorage, AK, for Knik Arm Bridge and Toll Authority, Anchorage, Alaska, Department of Transportation and Public Facilities, Anchorage, AK, and Federal Highway Administration, Juneau, Alaska. December 9. 232 p.

Gabriele, C.M. and B. Kipple. 2009. Measurements o f near-surface, near-bow underwater sound from cruise ships. Abstracts of the 18th Biennial Conference on the Biology of Marine Mammals, Quebec, Oct 2009, p. 86.

Gedamke, J., S. Frydman, and N. Gales. 2008. Risk of baleen whale hearing loss from seismic surveys: preliminary results from simulations accounting for uncertainty and individual variation. International Whaling Commission Working Paper SC/60/E9. 10pp.

Goetz, K. T., Montgomery, R. A., Ver Hoef, J. M., Hobbs, R. C., Johnson, D. S. 2012a. Identifying essential summer habitat of the endangered beluga whale *Delphinapterus leucas* in Cook Inlet, Alaska. Endangered Species Res 16, 135-147.

Goetz, K. T., P. W. Robinson, R. C. Hobbs, K. L. Laidre, L. A. Huckstadt, and K. E. W. Shelden. 2012b. Movement and dive behavior of beluga whales in Cook Inlet, Alaska. AFSC Processed Rep. 2012-03, 40 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Gordon, J., D. Gillespie, J. Potter, A. Frantzis, M.P. Simmonds, R. Swift, and D. Thompson. 2004. A review of the effects of seismic surveys on marine mammals. Marine Technology Society Journal 37:16-34.

Greene, C.R. Jr., N.S. Altman, and W.J. Richardson. 1999. Bowhead whale calls. In: W.J. Richardson (ed), Marine Mammal and Acoustical Monitoring of Western Geophysical's open water seismic program in the Alaskan Beaufort Sea. LGL rep TA2230-3 from LGL Ltd, King City, ON and Greeneridge Sciences Inc., Santa Barbara, CA. 390 p.

Hastings, M.C. and A.N. Popper. 2005. Effects of Sound on Fish. Subconsultants to Jones & Stokes under California Department of Transportation Contract No. 43A0139. August 23.

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.

Hildebrand, J.A. 2005. Impacts of anthropogenic sound. Pp. 101-124, In: J.E. Reynolds, W.F. Perrin, R.R. Reeves, S. Montgomery and T. Ragen (eds.), Marine Mammal Research: Conservation Beyond Crisis. Johns Hopkins Univ. Press, Baltimore, MD. 223 p.

Hobbs, R.C., D. J. Rugh, and D. P. DeMaster. 2000. Abundance of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska, 1994-2000. Marine Fisheries Review 62:37-45.

Hobbs, R.C., K.L. Laidre, D.J. Vos, B.A. Mahoney, and M. Eagleton. 2005. Movements and area use of belugas, *Delphinapterus leucas*, in a subarctic estuary. Arctic 58(4):33 1-340.

Hobbs, R. C., K. E. W. Shelden, D. J. Rugh, and S. A. Norman. 2008. 2008 status review and extinction risk assessment of Cook Inlet belugas. AFSC Processed Report 2008-02, 116 p. Alaska Fisheries Science Center, NOAA, National Marine Fisheries Service. 7600 Sand Point Way NE, Seattle, WA 98115.

Hobbs, R.C., C.L. Sims, and K.E.W. Sheldon. 2011. Estimated abundance of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska, from aerial surveys conducted in June 2011. NMFS, NMML Unpublished Report. 7p.

Hoover, A., A. 1988. Harbor Seal and Steller Sea Lion. In Selected Marine Mammals of Alaska, Species Accounts with Research and Management Recommendations. Jack W. Lentfer, ed., Marine Mammal Commission, 1988.

Huntington, H.P. 2000. Traditional knowledge of the ecology of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska. Marine Fisheries Review 62: 134- 140.

Ireland, D. S., D. W. Funk, T. M. Markowitz, and C. C. Kaplan. 2005. Beluga whale distribution and behavior in Eagle Bay and the Sixmile Area of Upper Cook Inlet, Alaska, in September and October 2005. Rep. from LGL Alaska Research Associates, Inc., Anchorage, Alaska, in association with HDR Alaska, Inc., Anchorage, Alaska, for the Knik Arm Bridge and Toll Authority, Anchorage, AK, Department of Transportation and Public Facilities, Anchorage, Alaska, and the Federal Highway Administration, Juneau, Alaska.

Jepson, P.D., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, F. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham and A. Fernández. 2003. Gas-bubble lesions in stranded cetaceans. Nature 425(6958):575-576.

Johnson, C.S. 1991. Hearing thresholds for periodic 60 kHz tone pulses in the beluga whale. Journal of the Acoustical Society of America 89:2996-3001.

Kastak, D., B. Southall, B.L., R.D. Schusterman, and C.R. Kastak. 2005. Underwater temporary threshold shifts in pinnipeds: effects of noise level and duration. Journal of the Acoustical Society of America 118: 3154-3163.

Kastak, D., R.J. Schusterman, B.L. Southall, and C.J. Reichmuth. 1999. Underwater temporary threshold shift induced by octave-band noise in three species of pinniped. Journal of the Acoustical Society of America 106:1142-1148.

Kastak, D. and R.J. Schusterman. 1995. Aerial and underwater hearing thresholds for 100 Hz pure tones in two pinniped species. In: R.A. Kastelein, J.A. Thomas, and P.E. Nachtigall (eds), Sensory systems of aquatic mammals. De Spil Publisihsing, Woerden, Netherlands

Kastelein, R.A., P. Bunskoek, M. Hagedoorn, W.L. Au, and D. Haan. 2002. Audiogram of a harbor porpoise (*Phocoena phocoena*) measured with narrow-band frequency-modulated signals. Journal of the Acoustical Society of America 112:334-344.

Kastelein, R.A., R. van Schie, W. Verboom, and D. Haan. 2005. Underwater hearing sensitivity of a male and a female Steller sea lion (*Eumetopias jubatus*). Journal of the Acoustical Society of America 118:1820-1829.

Ketten, D.R. 1994. Functional analysis of whale ears: adaptations for underwater hearing. IEEE Proc. Underwater Acoustics 1:264-270.

Ketten, D. 1998. Marine mammal auditory systems: a summary of audiometric and anatomical data and its implications for underwater acoustic impacts. NOAA-TM-NMFS-SWFSC-256. 74p.

Kryter, K.D. 1985. The effects of noise on man. 2nd ed. Academic Press, Orlando, FL. 688pp.

Kryter, K.D. 1994. The handbook of hearing and the effects of noise. Academic Press, Orlando, FL. 673pp.

Laidre, K.L., Shelden, K.E.W., Rugh, D.J., and Mahoney, B.A. 2000. Beluga, *Delphinapterus leucas*, distribution and survey effort in the Gulf of Alaska. Marine Fisheries Review 62:27-36.

Leatherwood, J.S., W.E. Evans, and D.W. Rice. 1982. The whales, dolphins, and porpoises of the eastern north Pacific. A guide to their identification in the water. Naval Undersea Center, NUC TP 282. 175p.

Lesage, V., C. Barrette, M. C. S. Kingsley and B. L. Sjare. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River estuary, Canada. Marine Mammal Science 15: 65-84.

Lomac-MacNair, K.S., L.S. Kendall, and S. Wisdom. Marine Mammal Monitoring and Mitigation, 90-Day Report, May 6- September 30, 2012, Alaska Apache Corporation 3D Seismic Program, Cook Inlet, Alaska. Prepared by SAExploration 8240 Sandlewood Pl. Suite 102 Anchorage, AK and Fairweather Science 9525 King Street, Anchorage, AK. Prepared for Apache Alaska Corporation and National Marine Fisheries Service. 87 p.

Lucke, K., U. Siebert, P.A. Lepper, and M.-A. Blanchet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. Journal of the Acoustical Society of America 125(6):4060-4070.

Markowitz, T.M., T.L McGuire, and D.M. Savarese. 2007. Monitoring beluga whale (*Delphinapterus leucas*) distribution and movements in Turnagain Arm along the Seward Highway. LGL Research Associates, Inc. Final Report from LGL Alaska Research Associates, Inc. Prepared for HDR, Inc. on behalf of the Alaska Department of Transportation and Public Facilities.

Matkin C, 2009 Predation by Killer Whales in Cook Inlet in Western Alaska: An Integrated Approach. 2008-2009 North Gulf Ocean Society Project R0303-01.

McDonald, M.A., J.A. Hildebrand, and S.C. Webb. 1995. Blue and fin whales observed on a seafloor array in the Northeast Pacific. Journal of the Acoustical Society of America 98:712-721.

Miller, G.W., V.D. Moulton, R.A. Davis, M. Holst, P. Millman, A. MacGillivray, and D. Hannay. 2005. Monitoring seismic effects on marine mammals – southeastern Beaufort Sea, 2001-2002. In: S.L. Armsworthy, P.J. Crandfor, and K. Lee (eds), Offshore oil and gas environmental effects monitoring: approaches and technologies. Battelle Press, Columbus, OH.

Mooney, T.A., P.E. Nachtigall, M. Breese, S. Vlachos, and W.W.L. Au. 2009a. Predicting temporary threshold shifts in a bottlenose dolphin (*Tursiops truncatus*): the effects of noise level and duration. Journal of the Acoustical Society of America 125(3):1816-1826.

Mooney, T.A., P.E. Nachtigall, and S. Vlachos. 2009b. Sonar-induced temporary hearing loss in dolphins. Biology Letters 4(4):565-567.

Moore, S.E., K.E.W. Shelden, L.L. Litzky, B.A. Mahoney, and D.J. Rugh. 2000. Beluga, *Delphinapterus leucas*, habitat associations in Cook Inlet, Alaska. Marine Fisheries Review 62:60-80.

Moulton, M. M. 1997. Early Marine Residence, Growth, and Feeding by Juvenile Salmon in Northern Cook Inlet, Alaska. Alaska Fishery Research Bulletin 4:154-177.

Moulton, V.D. and J.W. Lawson. 2002. Seals, 2001, In . In: W.J. Richardson (ed), Marine Mammal and Acoustical Monitoring of Western Geophysical's open water seismic program in the Alaskan Beaufort Sea. LGL rep TA2230-3 from LGL Ltd, King City, ON and Greeneridge Sciences Inc., Santa Barbara, CA. 390 p.

Muslow, J. and C. Reichmuth. 2010. Psychophysical and electrophysiological aerial audiograms of a Steller sea lion (*Eumetopias jubatus*). Journal of the Acoustical Society of America 127:2692-2701.

Nachtigall, P.E., A.Y. Supin, J. Pawloski, and W.W.L. Au. 2004. Temporary threshold shifts after noise exposure in the bottlenose dolphin (*Tursiops truncatus*) measured using evoked auditory potentials. Marine Mammal Science 20(4):673-687.

National Marine Fisheries Service NMFS. 2000. Small takes of marine mammals incidental to specified activities; marine seismic-reflection data collection in southern California. Federal Registry 65(20):16374-16379.

NMFS. 2003. Subsistence Harvest Management of Cook Inlet Beluga Whales Final Environmental Impact Statement. July.

NMFS. 2008a. Final Supplemental Environmental Impact Statement – Cook Inlet Beluga Whale Subsistence Harvest. Anchorage, Alaska http://www.fakr.noaa.gov/protectedresources/whales/beluga/seis/default.htm

NMFS. 2008b. Final Conservation Plan for the Cook Inlet beluga whale (*Delphinapterus leucas*). National Marine Fisheries Service, Juneau, Alaska.

NMFS. 2008c. Recovery Plan for the Steller sea lion (*Eumetopias jubatus*). National Marine Fisheries Service, Juneau, Alaska.

NMFS. 2012a. Section 7 Consultation 3-D Seismic Surveys of Cook Inlet, Alaska by Apache Alaska Corporation. http://www.alaskafisheries.noaa.gov/protectedresources/whales/beluga/development/apache/bioprev052112.pdf

NMFS. 2012b. Section 7 Consultation 3-D Seismic Surveys of Cook Inlet, Alaska by Apache Alaska Corporation. http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/development/apache/bioprev052112.pdf

NMFS. 2013a. Section 7 Consultation 3-D Seismic Surveys of Cook Inlet, Alaska by Apache Alaska Corporation. http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/development/apache/bioprev121413.pdf

NMFS. 2013b. Takes of Marine Mammals Incidental to Specified Activities; Taking Marine Mammals Incidental to Seismic Survey in Cook Inlet, AK. Notice of Issuance of Incidental Take Authorization. National Marine Fisheries Service, National Oceanic and Atmospheric Administration. Federal Register Vol. 78, No. 37, 12720-12744.

NMFS. 2013c. Finding of No Significant Impact for Issuance of an Incidental Harassment Authorization for Seismic Survey in Cook Inlet, AK. U.S Department of Commerce, NOAA-NMFS. http://www.nmfs.noaa.gov/pr/pdfs/permits/apache_fonsi2013.pdf

National Marine Mammal Laboratory (NMML). 2004. Personal communication from Christy Sims, Marine Mammal Data Specialist. Regarding Opportunistic Marine Mammal Sightings (1999-2002) and beluga aerial survey data (1993-2004). Seattle, WA.

NMML. 2011. Personal communication from Manuel Castellote, Marine Mammal Acoustician. Regarding results of passive acoustic monitoring in Cook Inlet and harbor porpoise use of West Foreland Site. Seattle, WA. Teleconference with David Hannay, JASCO.

Nedwell, J.R., B. Edwards, A.W.H. Turnpenny, and J. Gordon. 2004. Fish and marine mammal audiograms: a summary of available information. Prepared by Fawley Aquatic Research Laboratories Ltd. Subacoustech Report 534R0214. September 3. Available at www.subacoustech.com.

Nieukirk, S.L., K.M. Stafford, D.K. Mellinger, R.P. Dziak, and C.G. Fox. 2004. Low frequency whale and seismic airgun sounds recorded in the mid-Atlantic ocean. Journal of the Acoustical Society of America 115:1832-1843.

Nordman, A.S., B.A. Bohne, and G.W. Harding. 2000. Histopathological differences between temporary and permanent threshold shift. Hearing Research 139:31-41.

Popper, A.N., and T.J. Carlson. 1998. Application of Sound and Other Stimuli to Control Fish Behavior. Transactions of the American Fisheries Society 127:673-707.

Prevel Ramos, A.P., M.J. Nemeth, and A.M. Baker. 2008. Marine mammal monitoring at Ladd Landing in Upper Cook Inlet, Alaska, from July through October 2007. Final report prepared by LGL Alaska Research Associates, Inc., Anchorage, Alaska for Drven Corporation, Anchorage, Alaska.

Prevel Ramos, A.P., T.M. Markowitz, D.W. Funk, and M.R. Link. 2006. Monitoring beluga whales at the Port of Anchorage: Pre-expansion observations, August-November 2005. Report from LGL Alaska Research Associates, Inc., Anchorage, Alaska, for Integrated Concepts & Research Corporation, the Port of Anchorage, Alaska, and the waterfront Department of Transportation Maritime Administration.

Richardson, W.J., C.R. Greene, C.I. Malme, and D.H. Thomson. 1995. Marine Mammals and Noise. Academic Press, Inc., San Diego, CA.

Richardson, W.J., B. Wursig, and C.R. Greene. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. Journal of the Acoustical Society of America 79:1117-1128.

Rugh, D.J., K.E.W. Shelden, and B. A. Mahoney. 2000. Distribution of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska, during June/July, 1993-2000. Marine Fisheries Review 62: 6-21.

Rugh, D.J., K.E.W. Shelden, B.A. Mahoney, and L.K. Litzky. 2001. Aerial Surveys of Belugas in Cook Inlet, Alaska, June 2001. http://www.alaskafisheries.noaa.gov/protectedresources/whales/beluga/surveyrpt2002.pdf

Rugh, D.J., B.A. Mahoney, L.K. Litzky, and B.K. Smith. 2002. Aerial Surveys of Belugas in Cook Inlet, Alaska. June 2002. http://www.alaskafisheries.noaa.gov/protectedresources/whales/beluga/surveyrpt2002.pdf.

Rugh, D.J., B.A. Mahoney, C.L. Sims, B.K. Smith, and R.C. Hobbs. 2003. Aerial Surveys of Belugas in Cook Inlet, Alaska, June 2003. http://www.fakr.noaa.gov/protectedresources/whales/beluga/ surveyrpt2003.pdf.

Rugh, D.J., B.A. Mahoney, and B. K. Smith. 2004a. Aerial surveys of beluga whales in Cook Inlet, Alaska, between June 2001 and June 2002. U.S. Dep. Commer. NOAA Tech. Memo. NMFS-AFSC-145.

Rugh, D.J., B.A. Mahoney, C.L. Sims, B.A. Mahoney, B.K. Smith, and R.C. Hobbs. 2004b. Aerial Surveys of Belugas in Cook Inlet, Alaska, June 2004. http://www.fakr.noaa.gov/protected resources/whales/beluga/survey/2004.pdf.

Rugh, D.J., K.E.W. Shelden, C.L. Sims, B.A. Mahoney, B.K. Smith, L.K. (Litzky) Hoberecht, and R.C. Hobbs. 2005a. Aerial surveys of belugas in Cook Inlet, Alaska, June 2001, 2002, 2003, and 2004. NOAA Technical Memorandum NMFS-AFSC-149. 71pp.

Rugh, D. J., K.T. Goetz, and B.A. Mahoney. 2005b. Aerial Surveys of Belugas in Cook Inlet, Alaska, August 2005. http://www.fakr.noaa.gov/protectedresources/whales/beluga/aerialsurvey05.pdf.

Rugh, D. J., K. T. Goetz, B. A. Mahoney, B. K. Smith, and T. A. Ruszkowski. 2005c. Aerial surveys of belugas in Cook Inlet, Alaska, June 2005. Unpublished Document. Natl. Mar. Mammal Lab., NMFS, NOAA, Alaska Fish. Sci. Cent., 7600 Sand Point Way, NE, Seattle, WA 98115. 17 p.

Rugh, D.J., K.T. Goetz, C.L. Sims, and B.K. Smith. 2006. Aerial surveys of belugas in Cook Inlet, Alaska, August 2006. Unpubl. NMFS report. 9 pp.

Rugh, D.J., K.T. Goetz, J.A. Mocklin, B.A. Mahoney, and B.K. Smith. 2007. Aerial surveys of belugas in Cook Inlet, Alaska, June 2007. Unpublished Document. NMFS report. 16 pp.

Rugh, D.J., K.E.W. Shelden, and R.C. Hobbs. 2010. Range contraction in a beluga whale population. Endangered Species Res. 12:69-75.

Scheifele, P. M., S. Andrew, R. A. Cooper, M. Darre, F. E. Musiek and L. Max. 2005. Indication of a lombard vocal response in the St. Lawrence River beluga. Journal of Acoustic Society of America 117: 1486-1492.

Schlundt, C.E., J.J. Finneran, D.A. Carder, and S.H. Ridgway. 2000. Temporary shift in masking hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. Journal of the Acoustical Society of America 107(6):3496-3508.

Shelden, K.E.W., D.J. Rugh, B.A. Mahoney, and M.E. Dahlheim. 2003. Killer Whale Predation on Belugas in Cook Inlet, Alaska: Implications for a Depleted Population. Marine Mammal Science 19(3):529-544.

Shelden, K.E., K.T. Goetz, L.V. Brattström, C.L. Sims, D.J. Rugh, and B.A. Mahoney. 2008. Aerial surveys of belugas in Cook Inlet, Alaska, June 2008. NMFS Report. 19 pp.

Shelden, K.E., K.T. Goetz, L.V. Brattström, C.L. Sims, D.J. Rugh, and R.C. Hobbs. 2009. Aerial surveys of belugas in Cook Inlet, Alaska, June 2009. NMFS Report. 19 pp.

Shelden, K.E., K.T. Goetz, L.V. Brattström, C.L. Sims, D.J. Rugh, and R.C. Hobbs. 2010. Aerial surveys of belugas in Cook Inlet, Alaska, June 2010. NMFS Report. 19 pp.

Shelden, K.E.W., C.L. Sims, L. Vate Brattström, J.A. Mocklin, and R.C. Hobbs. 2012. Aerial surveys of belugas in Cook Inlet, Alaska, June 2012. NMFS, NMML Unpublished Field Report. 18 p

Širović, A. and L.S. Kendall. 2009. Passive acoustic monitoring of beluga whales. Analysis Report. Prepared by Alaska Pacific University, Anchorage, Alaska, Prepared for the US Department of Transportation Maritime Administration, Port of Anchorage, and Integrated Concepts & Research Corporation, Anchorage, Alaska.

Small, R.J. 2010. Final Report. Acoustic Monitoring of Beluga Whales and Noise in Cook Inlet. http://www.alaskafisheries.noaa.gov/protectedresources/whales/beluga/acoustics/cib_acoustics-1007-0910.pdf

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, Special Issue 33.

Stanek, R. T. 1994. The subsistence use of beluga whale in Cook Inlet by Alaska Natives. 1993. Draft Final Report for year two, subsistence study and monitoring system No.50ABNF200055. Technical Paper No. 232. ADF&G, Juneau, Alaska. 23-pp.

Stone, C.J. 2003. The effects of seismic activity on marine mammals in the UK waters 1998-2000. JNCC report 323 Joun Nature Conservancy, Aberdeen, Scotland. 43 p.

Szymanski, M.D., D.E. Bain, K. Kiehl, S. Pennington, S. Wong, and K.R. Henry. 1999. Killer whale (*Orcinus orca*) hearing: Auditory brainstem response and behavioral audiograms. Journal of the Acoustical Society of America 106:1134-1141.

Taylor, B., Barlow, J., Pitman, R., Ballance, L., Klinger, T., DeMaster, D., Hildebrand, J., Urban, J., Palacios, D. and Mead, J. 2004. A call for research to assess risk of acoustic impact on beaked whale populations. Paper SC/56/E36 presented to the IWC Scientific Committee, July 2004, Sorrento, Italy. 4pp.

Thewissen, J.G.M., J.D. Sensor, J.C. George, R.S. Suydam, and M.C. Liberman. 2011. Assessment of auditory trauma in the inner ear of Arctic whales. Abstracts of the 19th Biennial Conference on the Biology of Marine Mammals. November 27–December 2, 2011. Tampa, FL.

USDC. 2013. Motion for Summary Judgment, Native Village of Chickaloon et al. vs. National Marine Fisheries Service et al. United States District Court for the District of Alaska. Case No. 3:12-cv-00102-SLG. Filed May 28, 2013.

Wade, P.R. and R.P. Angliss. 1997. Guidelines for assessing marine mammal stocks: Report of the GAMMS workshop April 3-5, 1996, Seattle, Washington. NOAA Technical Memorandum NMFS-OPR-12. Available from Office of Protected Resources, National Marine Fisheries Service, Silver Spring, MD. 93p.

Ward, W.D. 1970. Temporary threshold shift and damage-risk criteria for intermittent noise exposure. Journal of the Acoustical Society of America 48:561-574.

Ward, W.D. 1997. Effects of high-intensity sound. In M.J. Crocker (ed.), Encyclopedia of Acoustics, Volume III (pp. 1497-1507). John Wiley and Sons, New York.

Wolfe, R. J., J. A. Fall, and M. Riedel. 2009. The Subsistence Harvest of Harbor Seals and Sea Lions by Alaska Natives in 2008. Technical Paper No. 347. Alaska Department of Fish and Game, Division of Subsistence and Alaska Native Harbor Seal Commission.

Yost, W.A. 2000. Fundamentals of hearing: an introduction. 4th ed. Academic Press, New York. 349 pp. Zerbini, A.N., J.M. Waite, J.L. Laake, and P.R. Wade. 2006. Abundance, trends, and distribution of baleen whales off Western Alaska and the central Aleutian Islands. Deep-Sea Research 53:1772–1790.

APPENDIX A

Sound Source Verification of Land-Based Explosives

Memorandum

TO: Katie McCafferty (USACE)

CC: Mandy Migura (NMFS), Brad Smith (NMFS), Brian Hopper (NMFS), Scott Nish (SAE), Jeff Hastings (SAE), Rick Trupp (SAE), Rick Stolz (SAE), Suzan Simonds (SAE), Mike Reblin (Apache), Steve Adiletta (Apache), Lisa Parker (Apache)

FROM: Sheyna Wisdom (Fairweather Science)

RE: Sound Source Verification of Land-Based Explosives Results

1.0 SUMMARY

SAExploration, Inc. (SAE) conducted a sound source verification (SSV) survey to characterize the underwater received sound levels resulting from land-based explosives on 17-18 September, 2011 in Trading Bay for Apache Alaska Corporation. The following summarizes the methods and results of the SSV study.

Two acoustic teams, JASCO Applied Sciences (JASCO) and Illingworth & Rodkin, Inc. (I&R), were contracted by SAE to perform the SSV test. JASCO's SSV equipment consisted of three Ocean Bottom Hydrophone (OBH) autonomous seabed acoustic recording systems, two vessel-based real-time acoustic monitoring and data logging stations, and one 4-channel particle velocity and acceleration measurement system. I&R's equipment consisted of two vessel-based single channel hydrophone measurement systems.

The SSV test consisted of a total of seven shot locations beginning in the mudflats, three locations in the lowlands and spaced every half mile for 4 miles inland, a total of 24 holes. Each location had a 1 kg charge buried at 25 ft, a 2 kg buried at 25 ft, and a 4 kg charge buried at 35 ft. Further details on methods are provided below. The detonations and measurements were performed on 17 September at low tide from approximately 3:30 – 8:30 pm. The OBHs were deployed at approximately 3:30 pm and retrieved at approximately 9:30 pm. Environmental conditions were favorable for collection of visual and acoustic data with winds less than 5 knots, calms seas, slightly overcast, and no fog or wind.

In order to ensure Cook Inlet beluga whales were not exposed to underwater received levels exceeding the National Marine Fisheries Service (NMFS) Level B harassment criteria during this test, three Protected Species Observers (PSOs) were employed on the two vessels and in a twin-engine aircraft.

Received levels reported by JASCO and I&R are well below the NMFS criterion of 160 dB re 1 Pa rms from the OBH and real-time vessel based data logging systems.

2.0 LOCATION

The SSV test was performed in Trading Bay, West Cook Inlet, Alaska. The test location is in Township Section and Range S011N011W and S011N012W, near the town of Shirleyville (Figure 1). The test line extended 4 miles along the northwest side of Nikolai Creek. The SSV test will consist of a total of eight shot locations beginning in the mudflats, three locations in the lowlands and spaced every half mile for 4 miles inland, a total of 24 holes. Locations of the test shots and vessels are provided in Appendix A.

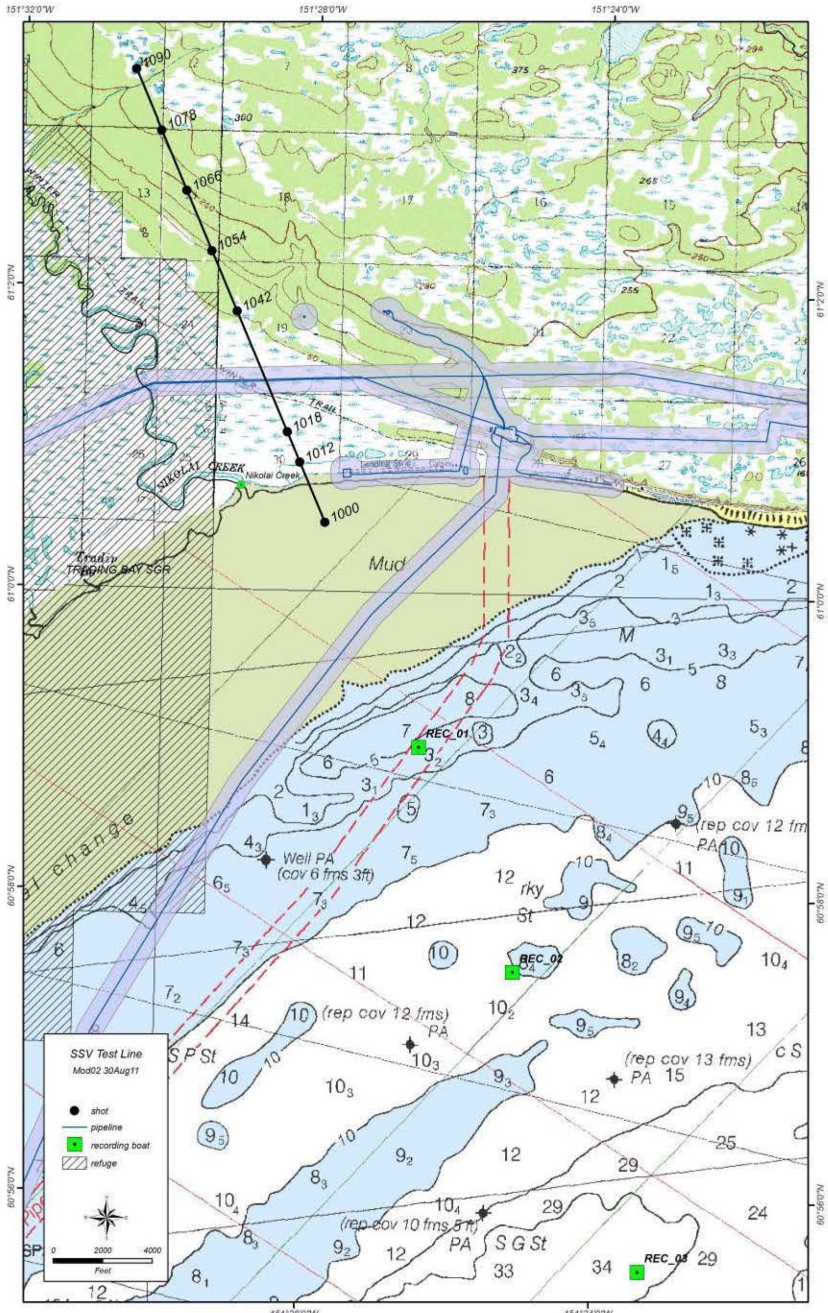


Figure 1. SSV test shothole location and OBH locations.

3.0 VESSELS

Two cable laying vessels, *the M/V Maxime* and *M/V Peregrine Falcon* were used for acoustic equipment deployment and retrieval (Figure 2). The *M/V Peregrine Falcon* is a 25 feet (ft) x 90 ft aluminum landing craft with a 32 inch draft and the *M/V Maxime* is a 16 ft x 70 ft aluminum landing craft. During the detonations, a Fast Response Craft (FRC) (e.g., 20-ft inflatable) was anchored at approximately 1 km from the last shothole on the test line. The particle sensor was deployed from the FRC. The *M/V Peregrine Falcon* was drifting at approximately 3 km from the last shothole on the test line. The JASCO real-time data logging system and I&R single channel hydrophone were deployed over the side of the vessel. The *M/V Maxime* was driving at approximately 6 km from the last shothole on the test line. The JASCO real-time data logging system and I&R single channel hydrophone were deployed over the side of the vessel. The actual locations of the vessels during the detonation are shown on Figure 3.

Figure 2. M/V Peregrine Falcon (left), M/V Maxime (right).

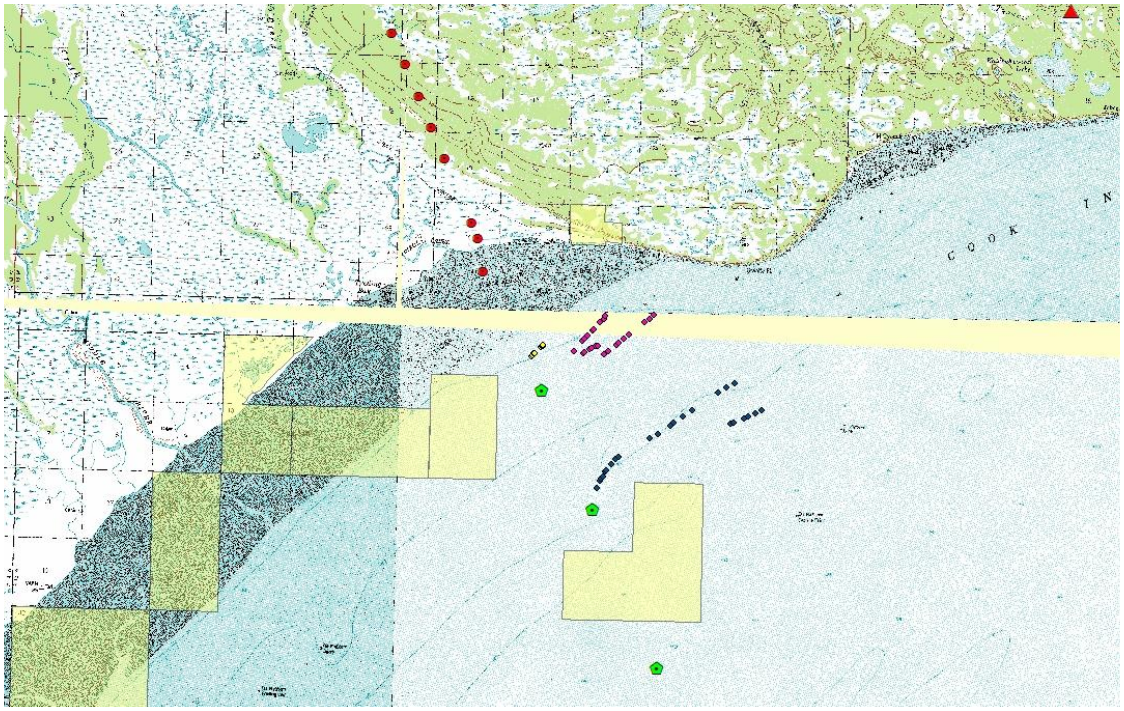


Figure 3. Locations of vessels during shothole detonations.
Yellow is zodiac with particle sensor, pink is *M/V Peregrine Falcon*, and gray is *M/V Maxime*.

4.0 PERSONNEL

The vessel crew was comprised of a captain and two deck hands for each vessel and one cook. The scientific team on the vessels consisted of three JASCO personnel (Caitlin O'Neil, Jennifer Wladichuk, Melanie Austin), two I&R personnel (James Reyff, Ryan Pommerenck), two PSOs (Sasha McFarland, Bridget Watts), and two project managers (Rick Stolz, Sheyna Wisdom). One PSO (Christa Koos) was on the aircraft (BN2 Islander twin turboprop) that flew over the site prior to the detonation to ensure there were no Cook Inlet beluga whales in the area.

5.0 ACOUSTIC MONITORING

Methods - JASCO

JASCO-operated equipment consisted of:

1. Three JASCO OBH autonomous seabed acoustic recording systems (Figures 4 and 5) deployed at 3 km, 6 km, and 10 km from the last shothole on the test line.

2. Two JASCO ADAMS/SpectroPlotter vessel-based real-time acoustic monitoring and data logging stations (Figure 6) deployed from vessels located at 3 km and 6 km from the last shothole on the testline. Vessels were drifting with engines off.

3. One 4-channel particle velocity and acceleration measurement system (Figure 7). The particle velocity sensor deployed from the FRC at approximately 1 km from the last shothole on the test line.

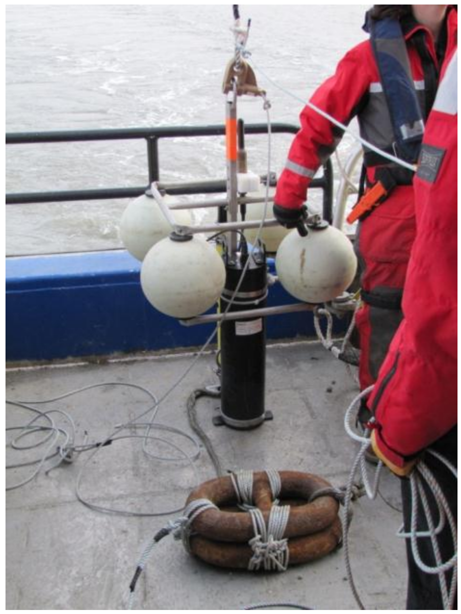


Figure 4. Ocean Bottom Hydrophone (OBH) autonomous acoustic recorders with float frames and integral acoustic releases.

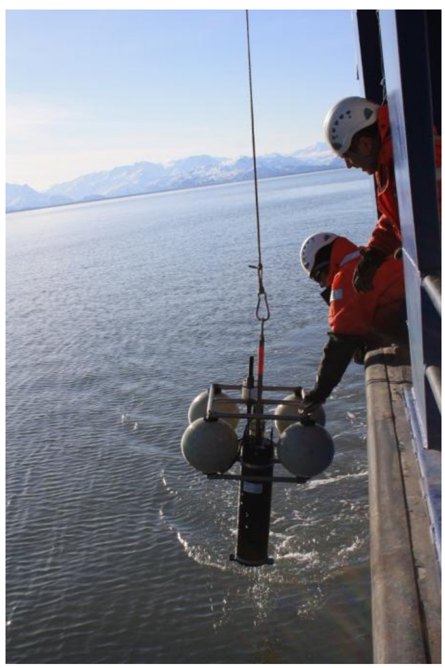


Figure 5. Deployment of OBH in Cook Inlet.

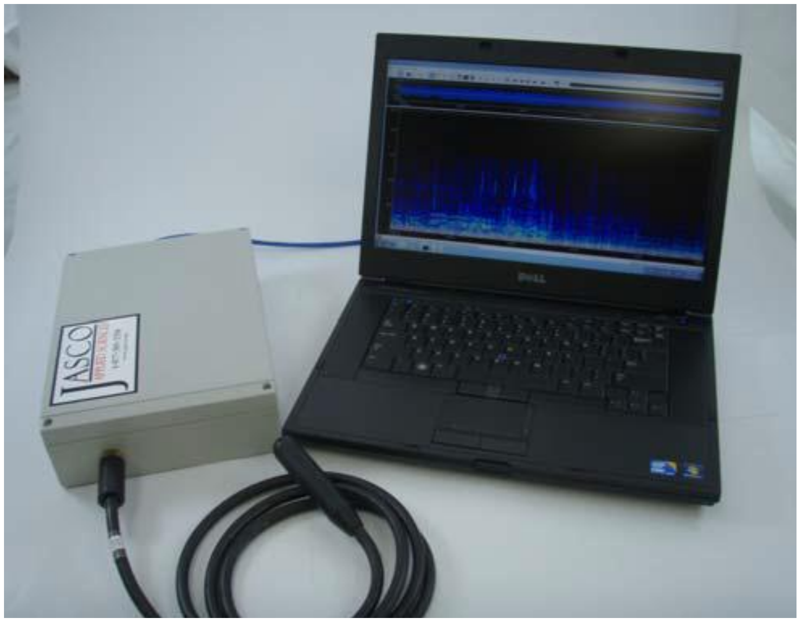


Figure 6. JASCO ADAMs digital acoustic monitoring system and SpectroPlotter real-time monitoring/logging software

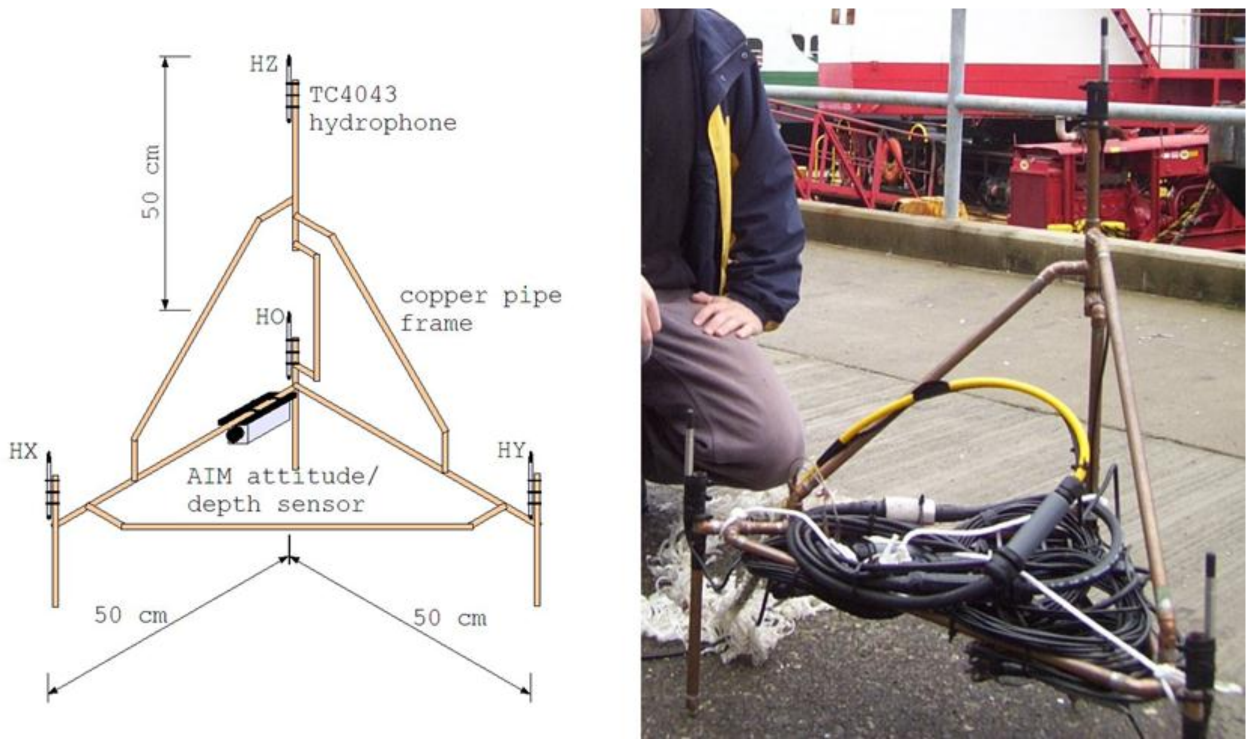


Figure 7. Four-hydrophone arrangement for particle velocity measurements using pressure gradient method.

Methods – I&R

I&R-operated equipment consisted of:

Two (2) single channel hydrophone measurement systems (Figure 8) consisting of hydrophones, signal charge converter, multigain signal conditioner, and dual channel digital audio recorder (sample rate up to 48 kHz). Sounds were recorded for subsequent analysis. The hydrophones were deployed over the side from vessels located on anchor at 3 km and 6 km from the last shothole on the test line.

On the *M/V Peregrine*, the hydrophone was a Reson TC-4103 miniature hydrophone connected to a PCB in-line charge amplifier and multi-gain power supply. The signal was split and fed into a Roland digital audio recorder and a Larson Davis Model 3000 Real Time Analyzer (RTA). The system was calibrated with a GRAS Type 42AC piston phone with a hydrophone coupler that produced a tone of 155.3 dB re 1 µPa at 250 Hz. On the *M/V Maxime*, the same system was used except a Larson Davis Model 820 Type 1 sound level meter was used instead of the RTA.

Figure 8. Two LDL Model 831 SLMs, recorder and one strung Reson TC-4033

Results – JASCO

JASCO analyzed the results from the three loudest shots recorded on the OBH and vessel-based data logging systems located 3 km from station 1000 (nearest shot to the vessels). For processing sound levels, the acoustic signals were low-pass filtered at 60 Hz to remove background noise (i.e., drilling rigs in the area) not related to the explosion shots. The over the side system was at a depth of 2 m and the OBH was approximately at a depth of 30 m, 1.5 m above the seafloor.

The sound levels measured on the shallow, over the side hydrophone were lower than on the OBH. This is to be expected, as low-frequency sounds are strongly attenuated near the sea surface due to the proximity of the pressure-release boundary.

Tables 1 and 2 summarize results of the test shothole location and Figure 9 shows a spectrogram plot of shot ID number 9 on OBH at 3022 m receiver range.

Table 1. Land explosion shots recorded by Ocean Bottom Hydrophone (OBH) at 3 km receiver range.

Shot ID Number	Station	Source Depth (ft)	Charge Size (kg)	Range (m)	0-Peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SEL (dB re 1 µPa2s)
1	1000	25	2	3022	142	134	130
8	1000	25	2	3022	142	131	130
9	1000	25	4	3022	144	131	132

Table 2. Land explosion shots recorded by over the side system at 3 km receiver range.

Shot ID Number	Station	Source Depth (ft)	Charge Size (kg)	Range (m)	0-Peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SEL (dB re 1 µPa2s)
1	1000	25	2	2794	117	109	106
8	1000	25	2	2957	117	106	107
9	1000	25	4	2992	124	110	114

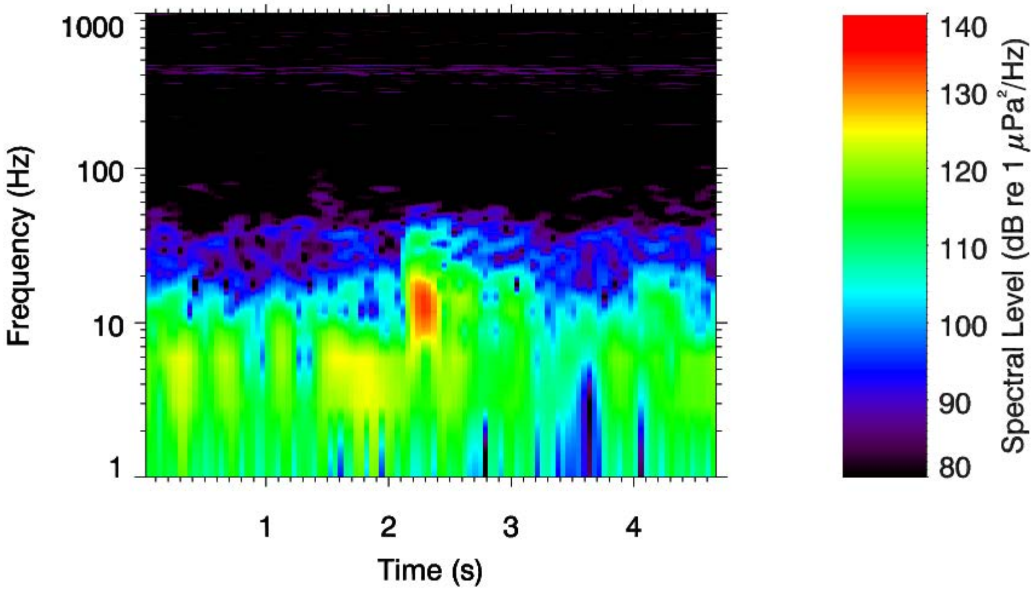


Figure 9. Spectrogram plot of land explosion shot ID number 9 on OBH at 3022 m receiver range

Results – I&R

I&R started the measurements when the project manager indicated the shots were "hot" and ended it after the shot was complete. The spectra charts shown in Appendix B show the maximum level (L_{max}) (the 1/8th of a second RMS detector) and the average equivalent energy level (L_{eq}) for the period measured. I&R reported received levels from 107-111 dB L_{eq} and 115-120 dB L_{max}, although it is important to note that these levels reported are not associated with the shot, as a signal was never detected during the study.

DISCUSSION

Received levels reported by JASCO and I&R are well below the NMFS criterion of 160 dB re 1 Pa rms from the OBH and real-time vessel based data logging systems.

MARINE MAMMAL MONITORING

Methods

Two PSOs observed from the two vessels: *M/V Peregrine* with eye height on bridge ~15 ft; visible horizon distance ~7.75km and *M/V Maxime* with eye height on bridge ~9 ft; visible horizon distance ~3km). Observers began observations 90 minutes prior to and during on-land and mudflat seismic activity. A third PSO conducted a site clearance overflight 30 minutes prior to seismic activity to ensure no beluga whales were in the area. One PSO was positioned on the port side of the bridge on each vessel and scanned the water to the horizon in the full field of view (~180 degrees forward). We recorded all marine mammal sightings. Variables recorded were: time of sighting, species, latitude and longitude of the vessel, position relative to the vessel, distance from vessel, number of animals in the sighting, color phase of belugas (white, gray, or black), behavior (including during and after shothole activity), closest point of approach time and distance, and any mitigation measures taken. We also recorded environmental conditions every 30 minutes, including water depth, Beaufort sea state, wind direction, % ice cover, % cloud cover, tidal stage, visibility, glare amount, and glare direction. Other variables we recorded were vessel speed and direction and whether or not seismic activities were underway.

Results

The *M/V Maxime* was positioned approximately 6 km from shore and did not observe any marine mammals during the shotholes. The *M/V Peregrine* was positioned approximately 3 km from shore and had seven marine mammal observations (Table 3), all positioned closer to shore than the observation platform. Both vessels drifted with the engines off during shothole detonations, but repositioned to compensate for movement with the current.

Table 3. Marine mammal sightings during SSV test of 17 September, 2011.

Time	Species	#	Distance from vessel (m)	Charge started? Y/N	Behavior	Mitigation measures taken Y/N	Comments
1553	Harbor seal	1	400	N	Look	N	Sank out of sight
1611	Harbor seal	1	500	N	Look	N	Sank; might be first
1619	Unidentified pinniped	1	1200	N	Rest	N	Sank
1626	Harbor seal	1	200	N	Look	N	Sank; might be first
1640	Harbor seal	1	600	N	Rest	N	Sank
1652	Harbor seal	1	350	Y	Rest	N	Mudflat shot initiated
1659	Harbor porpoise	1	250	Y	Travel	N	Inland shots ongoing

No beluga whales were sighted. The single harbor porpoise was sighted for three surfacings (approximately 10 to 30 seconds between each), and then not seen again in the monitoring area. Harbor seals were noted looking at the *M/V Peregrine* or at the FRC. Of the five harbor seals seen during the SSV test, three sightings were in approximately the same area and within 34 minutes time; this may have been a single curious animal investigating the vessels in the area. None of the animals sighted exhibited changes of behavior during the encounters.

Discussion

No Cook Inlet beluga whales were sighted before, during, or after the SSV.

APPENDIX A

GPS LOCATIONS OF SHOT HOLE RELATIVE TO VESSEL

Appendix A
Apache Alaska Corporation
Land-Based Explosives SSV
Sept 17, 2011
Zodiac Measurements

Type	SP	Lat (WGS-84)	Long (WGS-84)	Month#	Day#	Year	Hour	Min	Sec	Comment	Symbol#	SymbolColor	SymbolDisplay	Altitude (Meters)	Depth (Meters)	Temp Deg C	Ref Dist	Ref units
T	1000, 2 kg, 25'	60.98991754	-151.4459912	9	18	2011	0	54	28	-9.956543	1.00E+25	1.00E+25	M	0.0045	724.0696	724.0696	0.000904	5
T	1012, 1 kg, 25'	60.98991293	-151.4459867	9	18	2011	1	0	53	-9.956543	1.00E+25	1.00E+25	M	0.0045	724.8647	724.8647	0.000904	5
T	1000, 1 kg, 15'	60.9899121	-151.4459883	9	18	2011	1	2	48	-8.995239	1.00E+25	1.00E+25	M	0.0136	725.0838	725.0838	0.002712	5
T	1012, 4 kg, 30'	60.98991126	-151.445987	9	18	2011	1	4	53	-8.995239	1.00E+25	1.00E+25	M	0.0104	725.3077	725.3077	0.002072	5
T	1012, 2 kg, 25'	60.98990983	-151.4459846	9	18	2011	1	8	38	-10.437256	1.00E+25	1.00E+25	M	0.0093	725.6802	725.6802	0.001864	5
T	1000, 1 kg, 10'	60.98990983	-151.4459847	9	18	2011	1	9	33	-9.47583	1.00E+25	1.00E+25	M	0.0104	725.7352	725.7352	0.002072	5
T	1000, 2 kg, 25'	60.98990849	-151.4459792	9	18	2011	1	15	4	-9.956543	1.00E+25	1.00E+25	M	0.0136	726.3564	726.3564	0.002712	5
T	1000, 4 kg, 25'	60.98990757	-151.445976	9	18	2011	1	19	4	-10.437256	1.00E+25	1.00E+25	M	0.0104	726.7662	726.7662	0.002072	5
T	1000, 1 kg, 25'	60.98990606	-151.4459759	9	18	2011	1	21	24	-9.956543	1.00E+25	1.00E+25	M	0.0045	727.0182	727.0182	0.000904	5
T	1018, 1 kg, 25'	60.98990682	-151.4459554	9	18	2011	1	37	59	-8.514648	1.00E+25	1.00E+25	M	0.0531	729.9043	729.9043	0.01063	5
T	1018, 4 kg, 35'	60.98992308	-151.4459197	9	18	2011	1	40	54	-8.514648	1.00E+25	1.00E+25	M	0.1071	732.5627	732.5627	0.021414	5
T	1018, 2 kg, 22'	60.98996591	-151.4458041	9	18	2011	1	46	39	-8.033936	1.00E+25	1.00E+25	M	0.1104	740.4203	740.4203	0.022072	5
T	1042, 2 kg, 25'	60.98997957	-151.4457686	9	18	2011	1	48	19	-8.514648	1.00E+25	1.00E+25	M	0.133	742.8656	742.8656	0.026606	5
T	1042, 4 kg, 35'	60.99001578	-151.4456852	9	18	2011	1	51	54	-8.514648	1.00E+25	1.00E+25	M	0.1915	748.9072	748.9072	0.038293	5
T	1042, 1 kg, 25'	60.99011192	-151.4454835	9	18	2011	1	55	15	-8.514648	1.00E+25	1.00E+25	M	0.2309	764.1707	764.1707	0.046179	5
T	1090, 1 kg, 25'	60.99050738	-151.4447552	9	18	2011	2	4	30	-8.033936	1.00E+25	1.00E+25	M	0.7245	823.1652	823.1652	0.144907	5
T	1090, 4 kg, 25'	60.99056857	-151.4446481	9	18	2011	2	6	45	-7.553101	1.00E+25	1.00E+25	M	0.5138	832.0936	832.0936	0.102766	5
T	1090, 2 kg, 25'	60.99064727	-151.4445126	9	18	2011	2	9	20	-8.033936	1.00E+25	1.00E+25	M	0.2922	843.4984	843.4984	0.058435	5
T	1078, 1 kg, 25'	60.9919603	-151.4419157	9	18	2011	3	12	20	-10.917847	1.00E+25	1.00E+25	M	0.5859	1457.1315	1457.1315	0.117177	5
T	1066, 1 kg, 25'	60.9919893	-151.4418427	9	18	2011	3	13	5	-10.917847	1.00E+25	1.00E+25	M	0.6164	1462.2217	1462.2217	0.123272	5
T	1078, 4 kg, 35'	60.99209533	-151.4415623	9	18	2011	3	15	55	-11.398438	1.00E+25	1.00E+25	M	0.7935	1481.397	1481.397	0.158691	5
T	1066, 4 kg, 35'	60.9921442	-151.441428	9	18	2011	3	16	55	-9.47583	1.00E+25	1.00E+25	M	0.6435	1490.4537	1490.4537	0.128697	5
T	1078, 2 kg, 25'	60.99224051	-151.4411628	9	18	2011	3	18	55	-11.398438	1.00E+25	1.00E+25	M	0.6908	1508.3173	1508.3173	0.138162	5
T	1066, 2 kg, 25'	60.99228267	-151.4410476	9	18	2011	3	19	50	-11.398438	1.00E+25	1.00E+25	M	0.7242	1516.1028	1516.1028	0.144837	5

Appendix A
Apache Alaska Corporation
Land-Based Explosives SSV
Sept 17, 2011
M/V Peregrine Measurements (3 km)

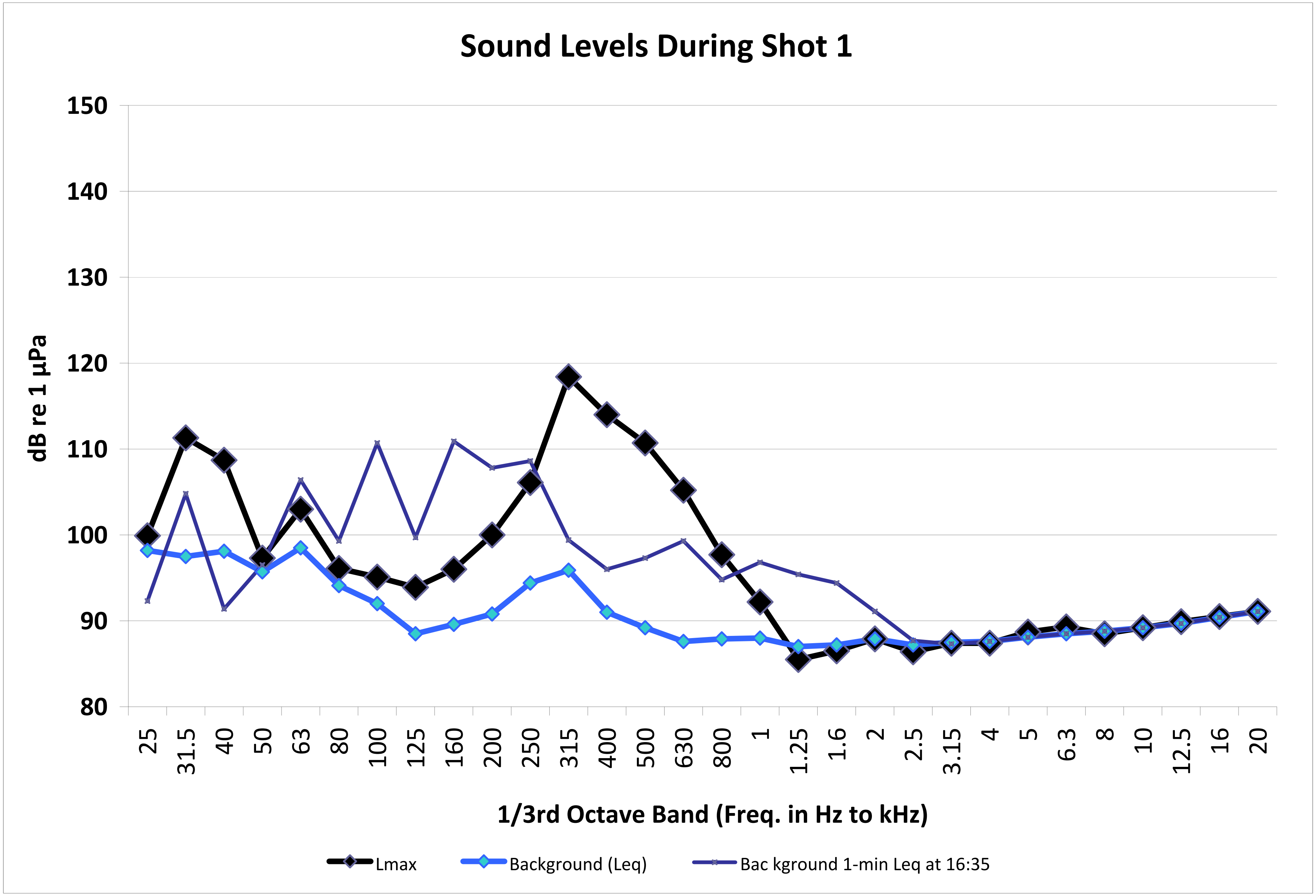
Type	SP	Lat (WGS-84)	Long (WGS-84)	Month#	Day#	Year	Hour	Min	Sec	Comment	Symbol#	SymbolColor	SymbolDisplay	Altitude (Meters)	Depth (Meters)	Temp Deg C	Ref Dist	Ref units
T	1000, 2 kg, 25'	60.99128891	-151.4275184	9	18	2011	0	54	25	-9.47583	1.00E+25	1.00E+25	M	4.3694	115.311	33279454.9	0.873877	5
T	1012, 1 kg, 25'	60.99334851	-151.4241399	9	18	2011	1	0	50	-11.398438	1.00E+25	1.00E+25	M	3.3304	418.0037	33279757.59	0.666083	5
T	1000, 1 kg, 15'	60.99389442	-151.4231465	9	18	2011	1	2	50	-11.398438	1.00E+25	1.00E+25	M	3.9199	503.4697	33279843.06	0.783979	5
T	1012, 4 kg, 30'	60.9945514	-151.4218887	9	18	2011	1	4	55	-11.398438	1.00E+25	1.00E+25	M	3.4539	605.7288	33279945.32	0.690778	5
T	1012, 2 kg, 25'	60.99560936	-151.4198625	9	18	2011	1	8	40	-12.359863	1.00E+25	1.00E+25	M	4.4164	778.0306	33280117.62	0.883288	5
T	1000, 1 kg, 10'	60.99589887	-151.419303	9	18	2011	1	9	30	-12.359863	1.00E+25	1.00E+25	M	3.0041	825.4883	33280165.07	0.60083	5
T	1000, 2 kg, 25'	60.9972953	-151.4165322	9	18	2011	1	15	5	-10.437256	1.00E+25	1.00E+25	M	2.5196	1054.324	33280393.91	0.50392	5
T	1000, 4 kg, 25'	60.99811287	-151.4151711	9	18	2011	1	19	5	-8.995239	1.00E+25	1.00E+25	M	2.2417	1181.1919	33280520.78	0.448348	5
T	1000, 1 kg, 25'	60.99861444	-151.414448	9	18	2011	1	21	25	-8.514648	1.00E+25	1.00E+25	M	2.2375	1253.7912	33280593.38	0.447505	5
T	1018, 1 kg, 25'	60.99061869	-151.4146858	9	18	2011	1	38	0	-11.398438	1.00E+25	1.00E+25	M	3.6331	2682.8585	33282022.45	0.726616	5
T	1018, 4 kg, 35'	60.99128581	-151.4130815	9	18	2011	1	40	50	-11.87915	1.00E+25	1.00E+25	M	4.306	2808.1364	33282147.72	0.861191	5
T	1018, 2 kg, 22'	60.99270101	-151.4095704	9	18	2011	1	46	35	-15.243652	1.00E+25	1.00E+25	M	2.9977	3068.359	33282407.95	0.599532	5
T	1042, 2 kg, 25'	60.99311926	-151.4085298	9	18	2011	1	48	20	-15.243652	1.00E+25	1.00E+25	M	4.1445	3144.6269	33282484.21	0.828903	5
T	1042, 4 kg, 35'	60.9940106	-151.4063459	9	18	2011	1	51	50	-13.801758	1.00E+25	1.00E+25	M	3.2603	3310.436	33282650.02	0.652058	5
T	1042, 1 kg, 25'	60.99497125	-151.4040654	9	18	2011	1	55	15	-13.321045	1.00E+25	1.00E+25	M	3.9478	3482.5438	33282822.13	0.789558	5
T	1090, 1 kg, 25'	60.99764843	-151.3973603	9	18	2011	2	4	30	-13.801758	1.00E+25	1.00E+25	M	4.0029	4002.4619	33283342.05	0.800588	5
T	1090, 4 kg, 25'	60.99834706	-151.395584	9	18	2011	2	6	45	-14.282471	1.00E+25	1.00E+25	M	4.1575	4127.1957	33283466.78	0.831508	5
T	1090, 2 kg, 25'	60.99914367	-151.3935282	9	18	2011	2	9	20	-14.282471	1.00E+25	1.00E+25	M	4.8923	4269.8134	33283609.4	0.978468	5
T	1078, 1 kg, 25'	60.99086126	-151.4237118	9	18	2011	3	12	22	-14.282471	1.00E+25	1.00E+25	M	5.1294	1552.4605	33289161.4	1.02588	5
T	1066, 1 kg, 25'	60.99102999	-151.4232123	9	18	2011	3	13	2	-13.801758	1.00E+25	1.00E+25	M	4.7472	1585.4591	33289194.4	0.949435	5
T	1078, 4 kg, 35'	60.99165168	-151.4207113	9	18	2011	3	15	57	-13.321045	1.00E+25	1.00E+25	M	4.5952	1747.0084	33289355.95	0.919035	5
T	1066, 4 kg, 35'	60.99191395	-151.419941	9	18	2011	3	16	57	-12.840454	1.00E+25	1.00E+25	M	5.3143	1798.8372	33289407.78	1.062865	5
T	1078, 2 kg, 25'	60.99229532	-151.4180942	9	18	2011	3	18	57	-12.840454	1.00E+25	1.00E+25	M	3.7352	1908.5827	33289517.52	0.747038	5
T	1066, 2 kg, 25'	60.99248459	-151.4173081	9	18	2011	3	19	47	-12.840454	1.00E+25	1.00E+25	M	5.6912	1956.4959	33289565.44	1.13825	5

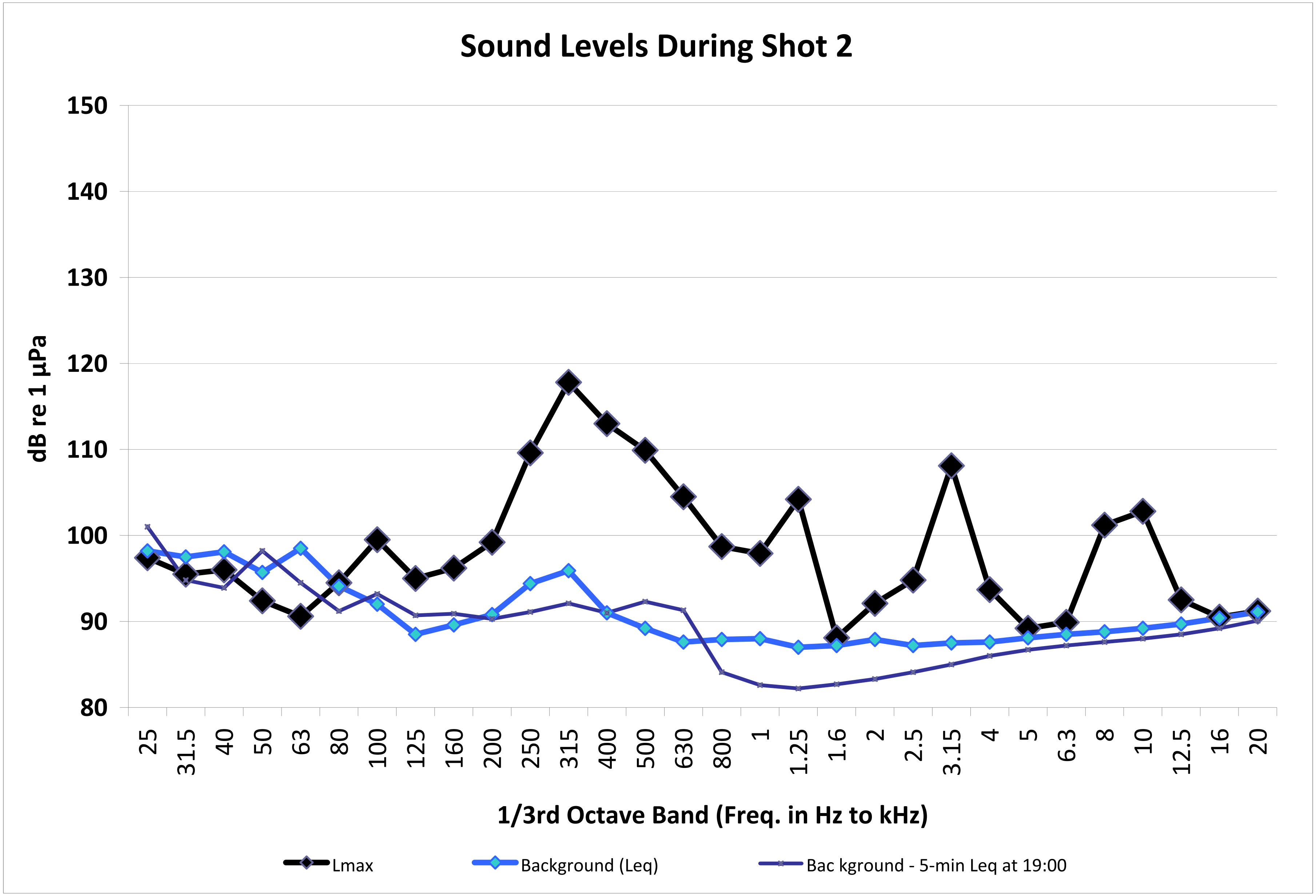
Appendix A
Apache Alaska Corporation
Land-Based Explosives SSV
Sept 17, 2011
M/V Maxime Measurements (6 km)

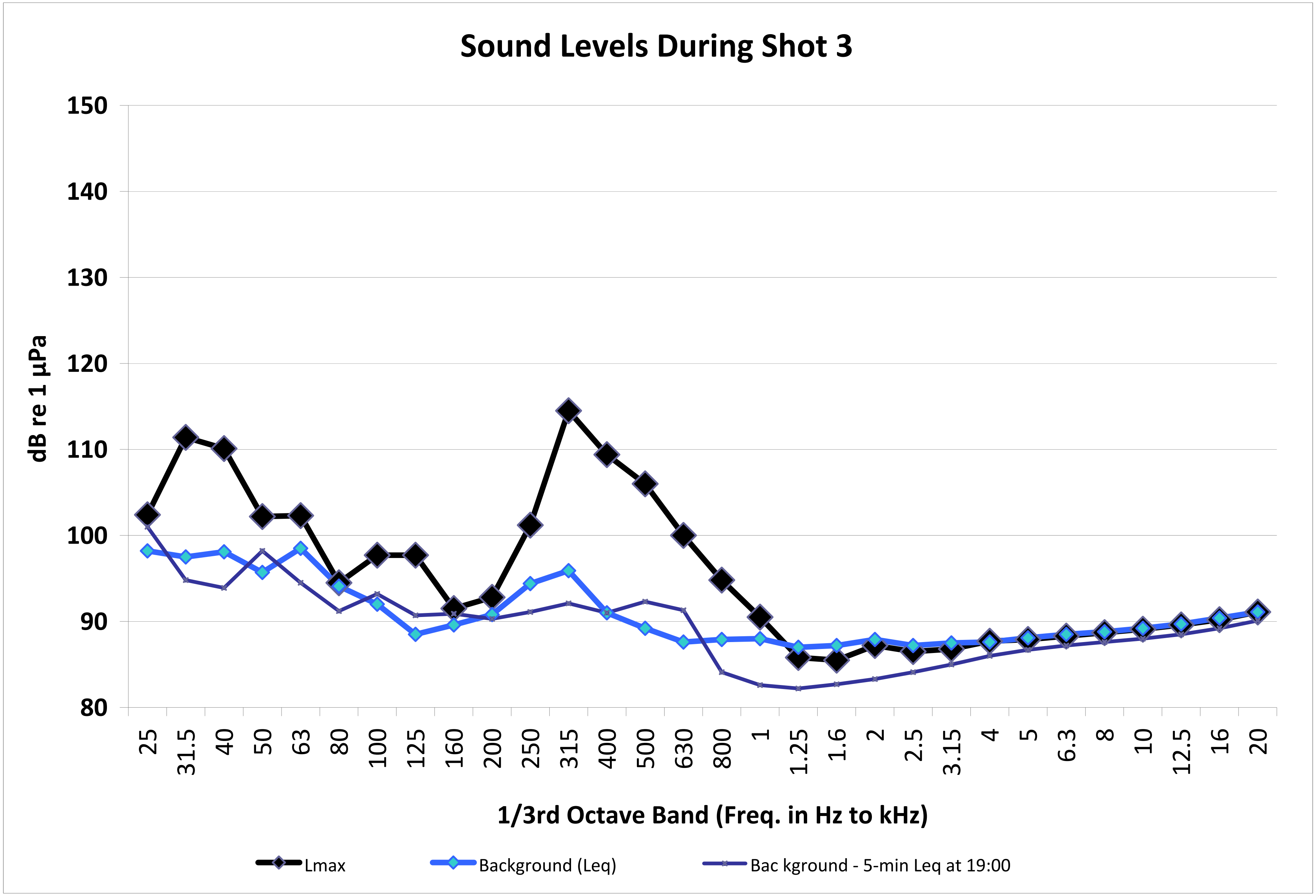
Type	SP	Lat (WGS-84)	Long (WGS-84)	Month#	Day#	Year	Hour	Min	Sec	Comment	Symbol#	SymbolColor	SymbolDisplay	Altitude (Meters)	Depth (Meters)	Temp Deg C	Ref Dist	Ref units
T	1000, 2 kg, 25'	60.96267309	-151.4163099	9	18	2011	0	54	33	16.960449	1.00E+25	1.00E+25	SM	0.0129	0.2667	3.8366	1.225251	38
T	1012, 1 kg, 25'	60.96421025	-151.4150674	9	18	2011	1	0	35	13.595825	1.00E+25	1.00E+25	SM	0.015	0.384	3.9538	1.289817	42
T	1000, 1 kg, 15'	60.96466547	-151.4146214	9	18	2011	1	2	26	10.711792	1.00E+25	1.00E+25	SM	0.0112	0.4188	3.9886	1.116323	36
T	1012, 4 kg, 30'	60.96518942	-151.4140437	9	18	2011	1	4	32	-0.343384	1.00E+25	1.00E+25	SM	0.012	0.4599	4.0298	1.053849	41
T	1012, 2 kg, 25'	60.96631846	-151.412938	9	18	2011	1	8	49	0.137451	1.00E+25	1.00E+25	SM	0.01	0.547	4.1169	1.236434	29
T	1000, 1 kg, 10'	60.96654679	-151.4127251	9	18	2011	1	9	32	2.540649	1.00E+25	1.00E+25	SM	0.0173	0.5643	4.1342	1.44979	43
T	1000, 2 kg, 25'	60.9678671	-151.4106768	9	18	2011	1	14	51	-5.149902	1.00E+25	1.00E+25	SM	0.0104	0.6787	4.2486	1.134143	33
T	1000, 4 kg, 25'	60.96891803	-151.4087569	9	18	2011	1	19	7	-5.630493	1.00E+25	1.00E+25	SM	0.0162	0.7763	4.3461	1.423388	41
T	1000, 1 kg, 25'	60.96943351	-151.4073062	9	18	2011	1	21	23	0.618042	1.00E+25	1.00E+25	SM	0.0203	0.8367	4.4065	1.623903	45
T	1018, 1 kg, 25'	60.97328542	-151.3941622	9	18	2011	1	37	49	-4.188599	1.00E+25	1.00E+25	SM	0.0192	1.3541	4.9239	2.155318	32
T	1018, 4 kg, 35'	60.97427306	-151.3908138	9	18	2011	1	41	7	-17.166382	1.00E+25	1.00E+25	SM	0.0271	1.4855	5.0554	2.4354	40
T	1018, 2 kg, 22'	60.97609168	-151.3854634	9	18	2011	1	46	41	-4.669312	1.00E+25	1.00E+25	SM	0.026	1.7046	5.2745	2.343729	40
T	1042, 2 kg, 25'	60.97661798	-151.3840703	9	18	2011	1	48	8	-3.707886	1.00E+25	1.00E+25	SM	0.0294	1.764	5.3339	2.585043	41
T	1042, 4 kg, 35'	60.97808423	-151.3803036	9	18	2011	1	51	49	-10.437256	1.00E+25	1.00E+25	SM	0.0184	1.926	5.4959	3.017529	22
T	1042, 1 kg, 25'	60.97949624	-151.3764597	9	18	2011	1	55	31	4.463257	1.00E+25	1.00E+25	SM	0.0232	2.0877	5.6576	2.089307	40
T	1090, 1 kg, 25'	60.98324094	-151.3651237	9	18	2011	2	4	17	3.982666	1.00E+25	1.00E+25	SM	0.0301	2.5946	6.1645	2.777337	39
T	1090, 4 kg, 25'	60.98422129	-151.3618725	9	18	2011	2	6	39	5.424561	1.00E+25	1.00E+25	SM	0.0504	2.723	6.2928	3.487922	52
T	1090, 2 kg, 25'	60.98530591	-151.3582288	9	18	2011	2	9	12	0.618042	1.00E+25	1.00E+25	SM	0.0452	2.8664	6.4363	3.321894	49
T	1078, 1 kg, 25'	60.97674119	-151.3594436	9	18	2011	3	12	15	5.905273	1.00E+25	1.00E+25	SM	0.0442	7.6506	11.2204	3.877627	41
T	1066, 1 kg, 25'	60.97695476	-151.3584596	9	18	2011	3	12	52	5.905273	1.00E+25	1.00E+25	SM	0.0361	7.6867	11.2566	3.515989	37
T	1078, 4 kg, 35'	60.97797149	-151.3538491	9	18	2011	3	15	44	0.137451	1.00E+25	1.00E+25	SM	0.0264	7.8566	11.4264	3.80736	25
T	1066, 4 kg, 35'	60.97837516	-151.3521358	9	18	2011	3	16	48	-2.746704	1.00E+25	1.00E+25	SM	0.0378	7.9204	11.4903	3.677114	37
T	1078, 2 kg, 25'	60.97907555	-151.3489779	9	18	2011	3	18	40	0.137451	1.00E+25	1.00E+25	SM	0.0395	8.0369	11.6067	4.061812	35
T	1066, 2 kg, 25'	60.97963211	-151.3464417	9	18	2011	3	20	6	2.540649	1.00E+25	1.00E+25	SM	0.0521	8.1302	11.7	3.830052	49

APPENDIX B

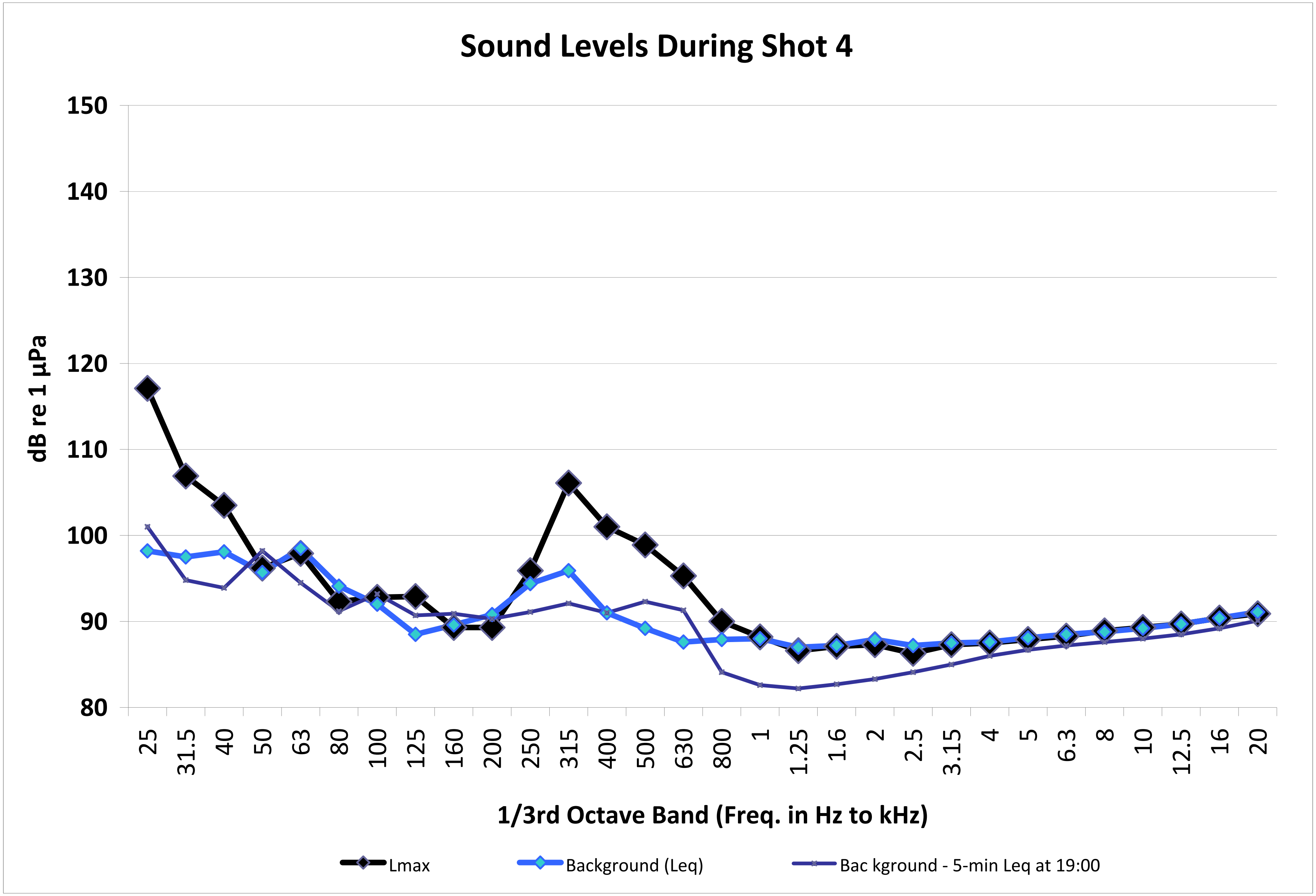
RESULTS OF I&R FROM M/V PEREGRINE


Sound Levels During Shot 1
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)
Bac kground 1-min Leq at 16:35

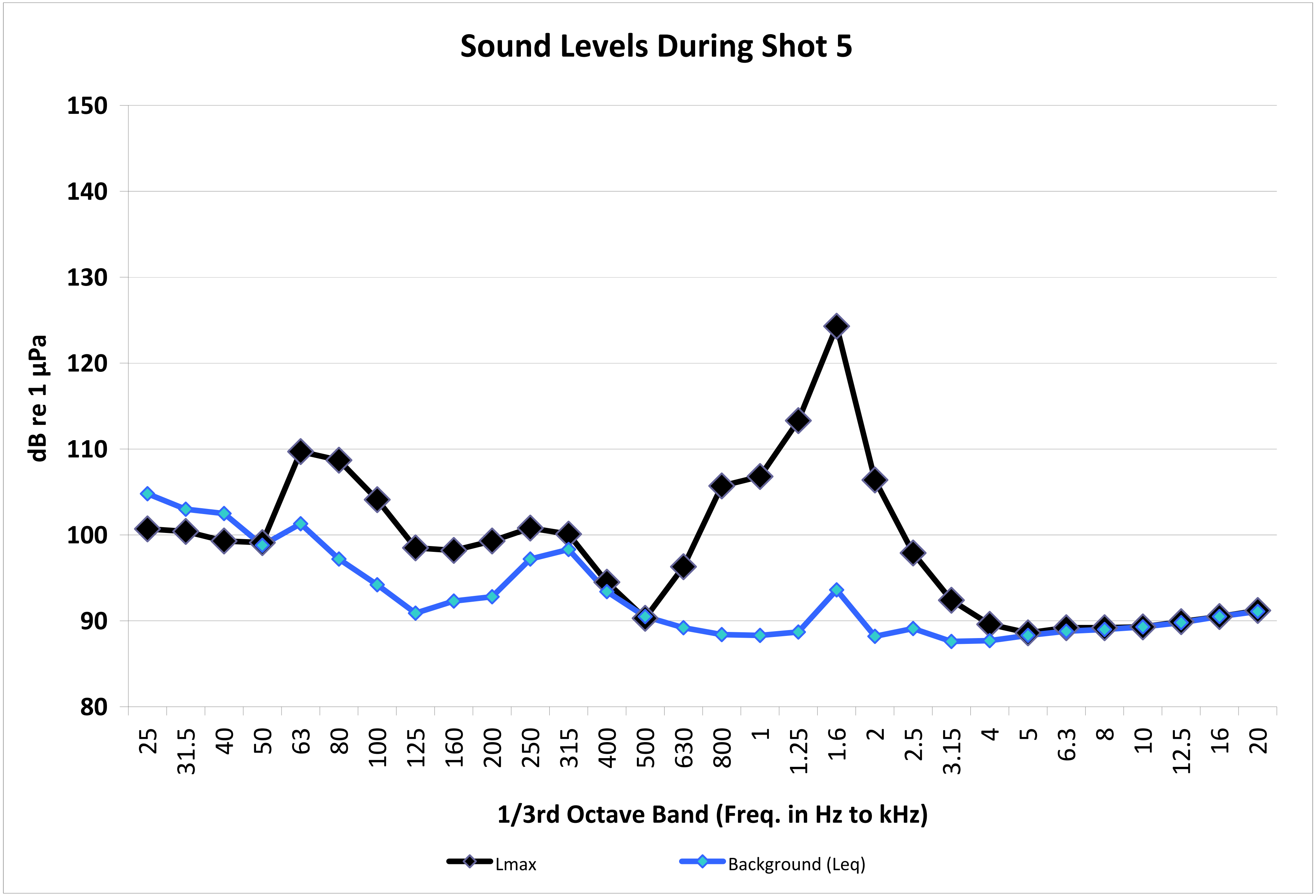

Sound Levels During Shot 2
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)
Bac kground - 5-min Leq at 19:00

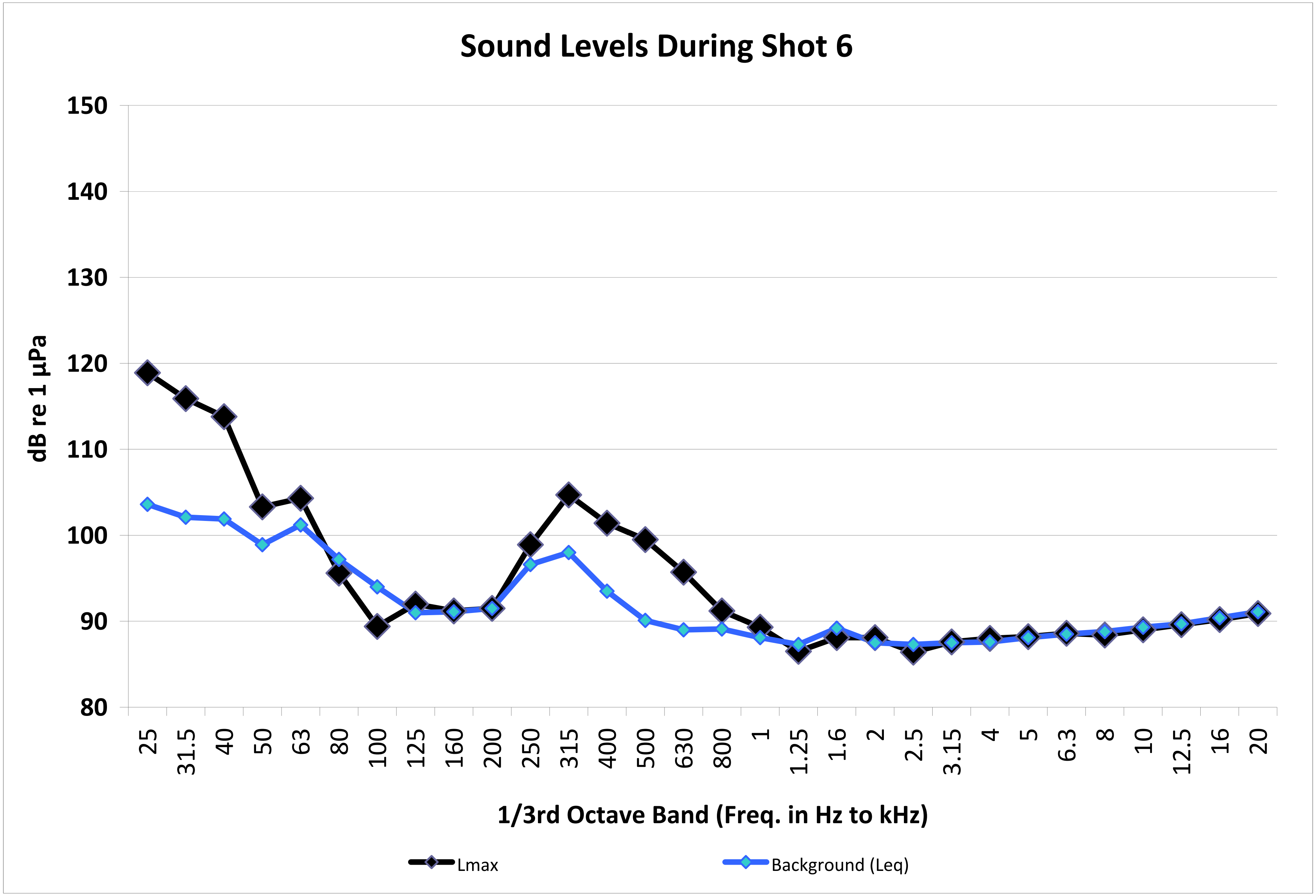


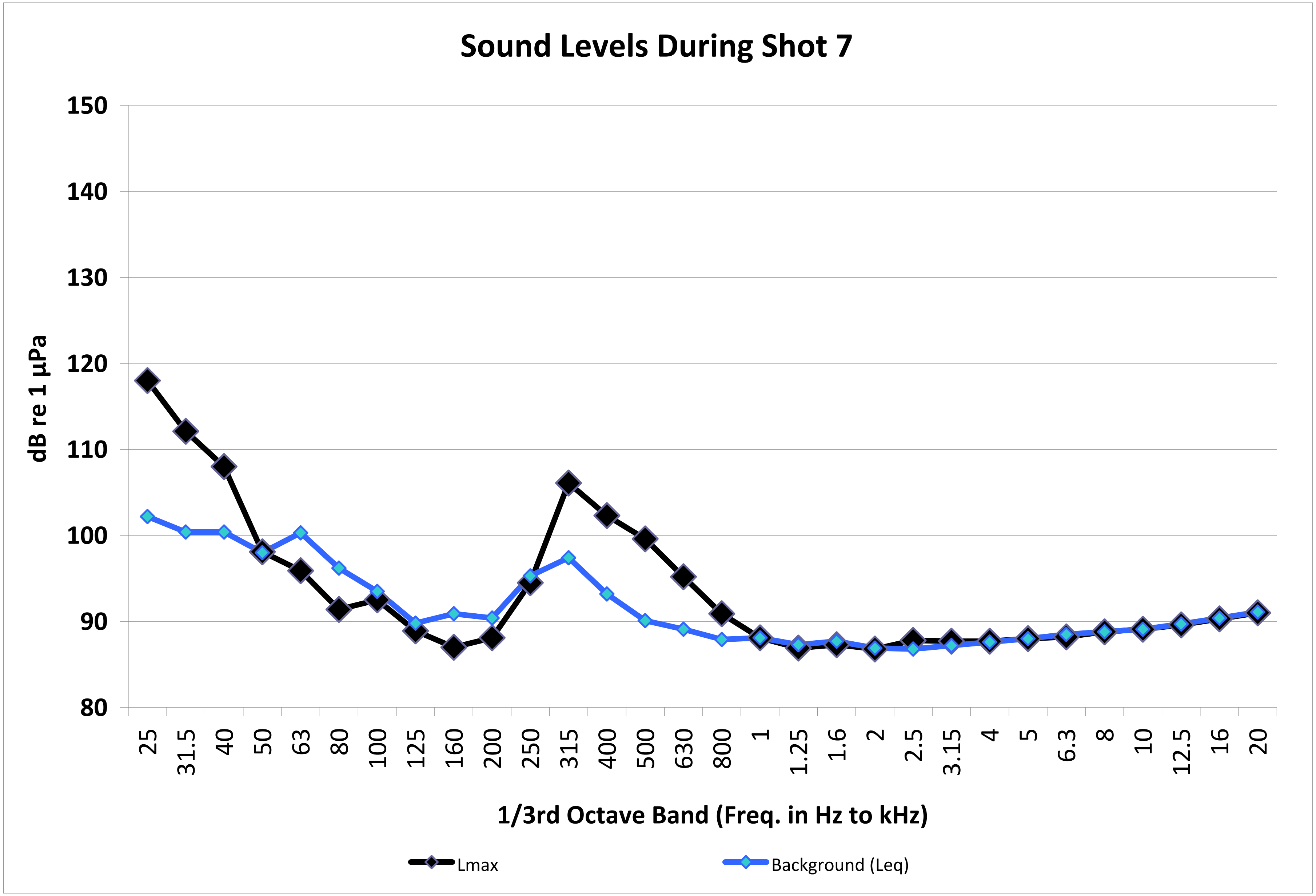
Sound Levels During Shot 3
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)
Bac kground - 5-min Leq at 19:00

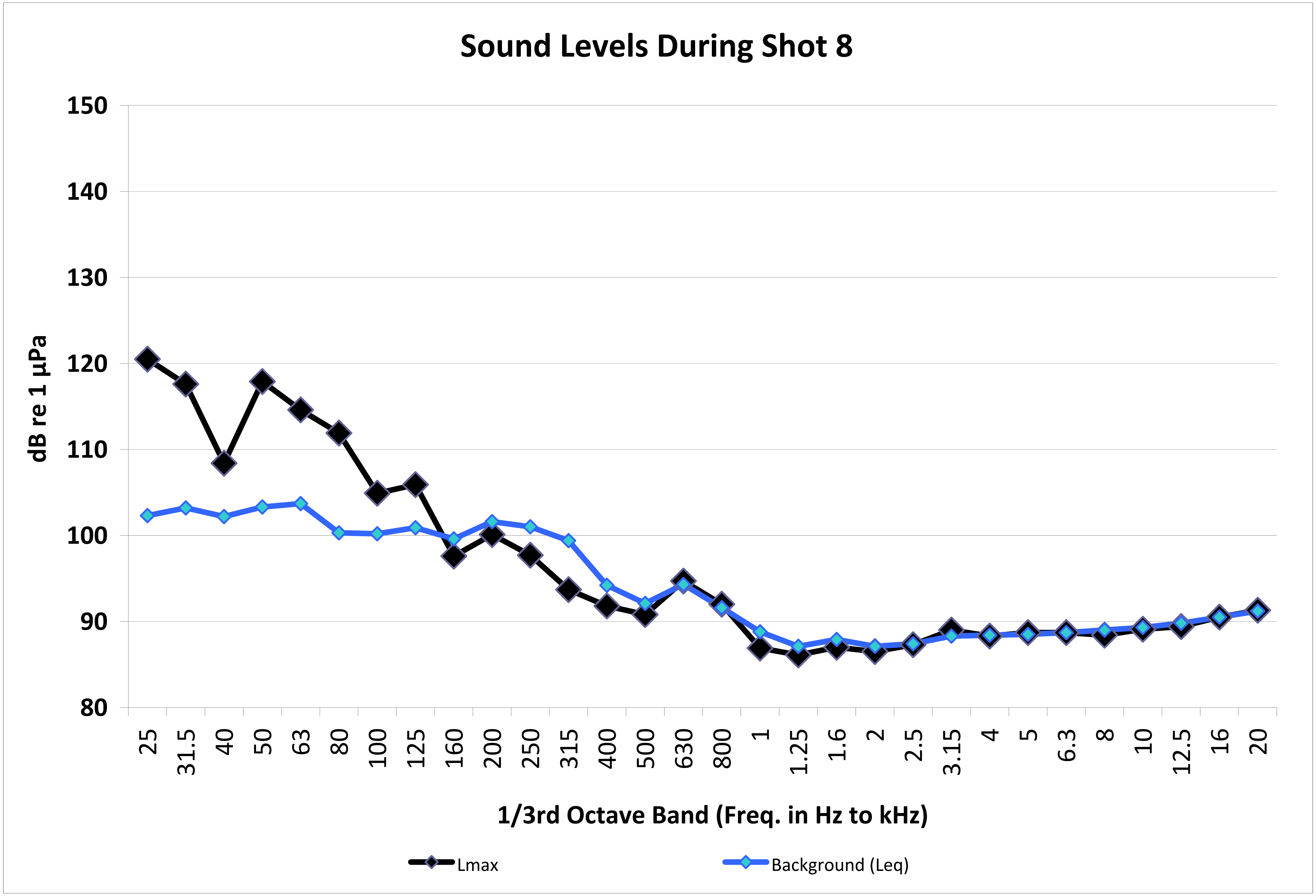


Sound Levels During Shot 4
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)
Bac kground - 5-min Leq at 19:00

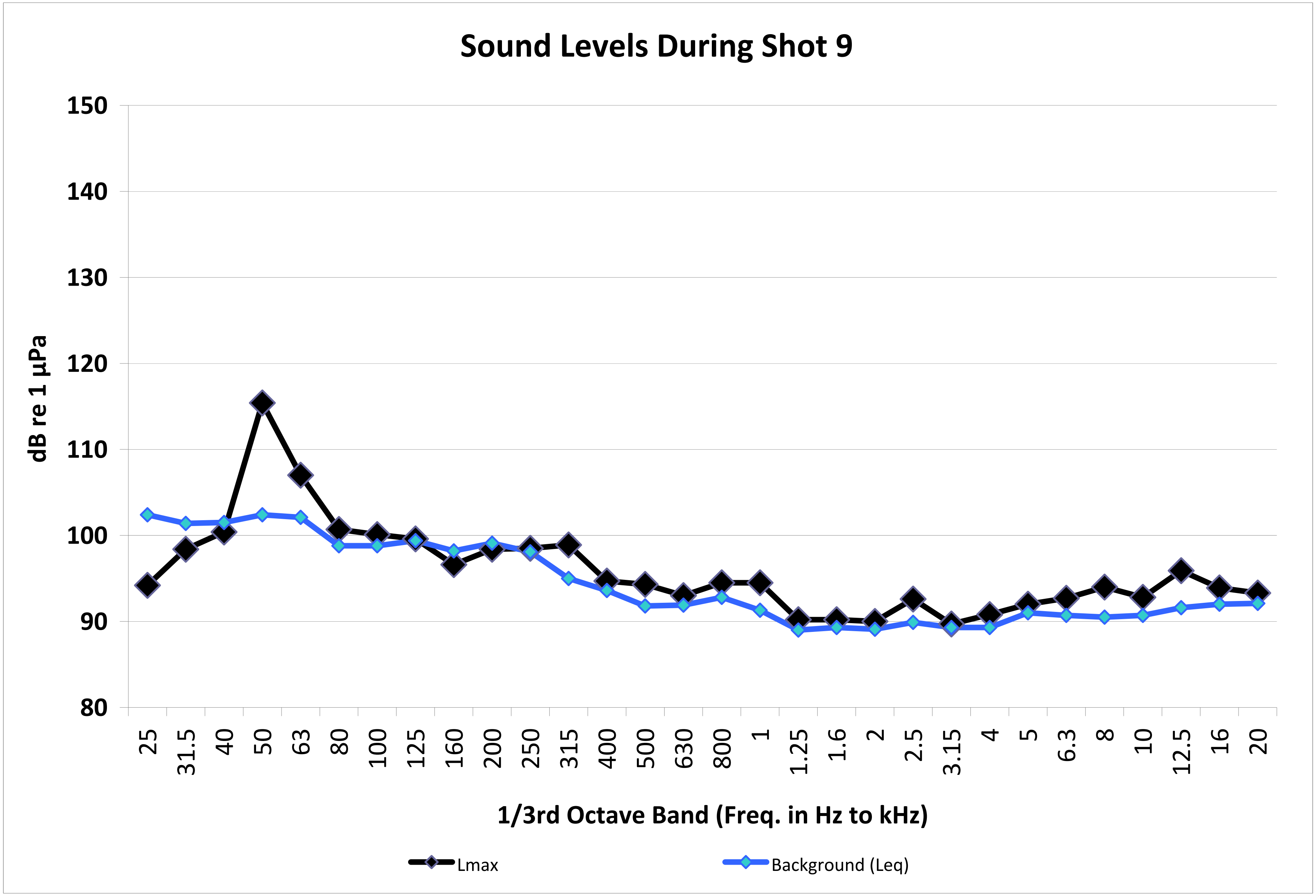

Sound Levels During Shot 5
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)

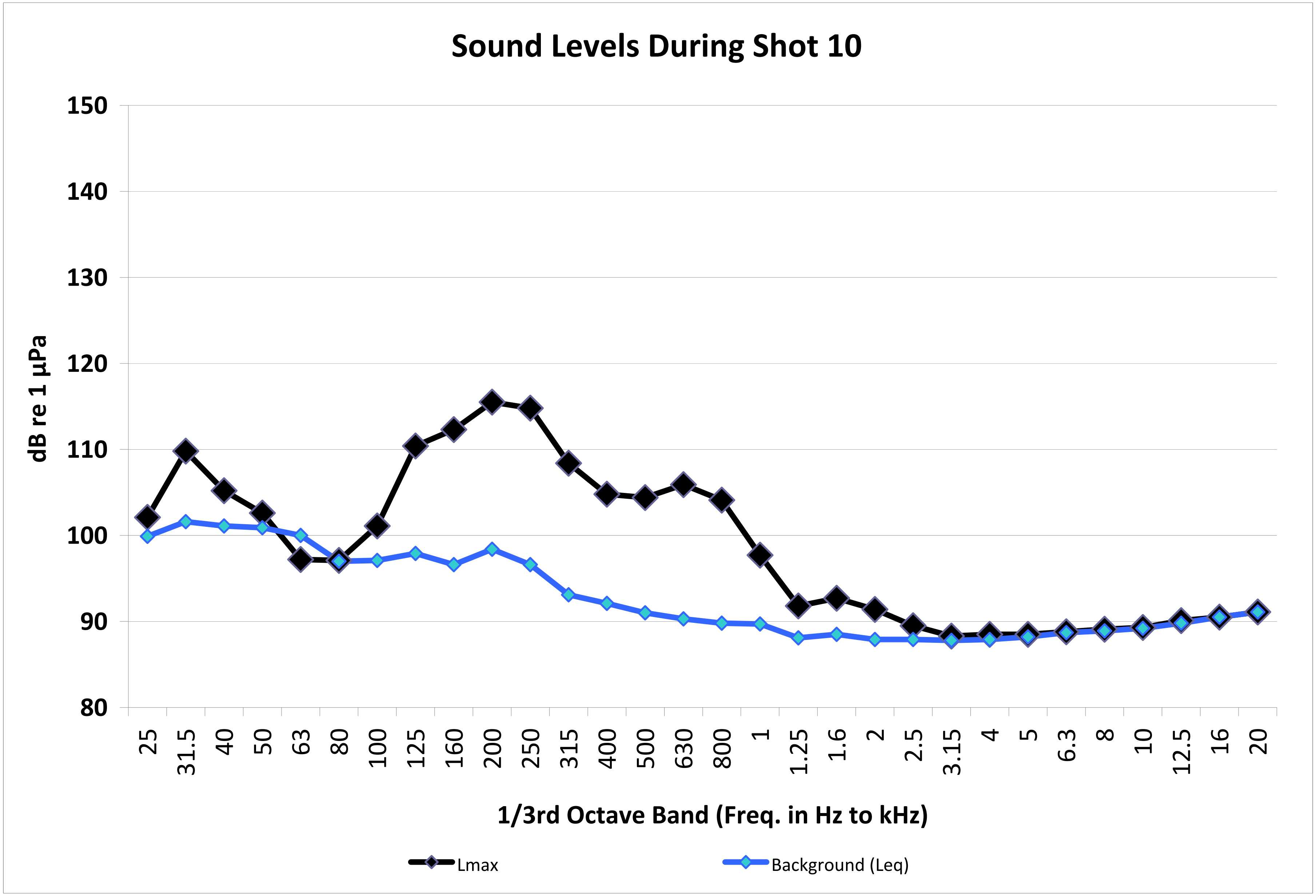

Sound Levels During Shot 6
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)


Sound Levels During Shot 7
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)

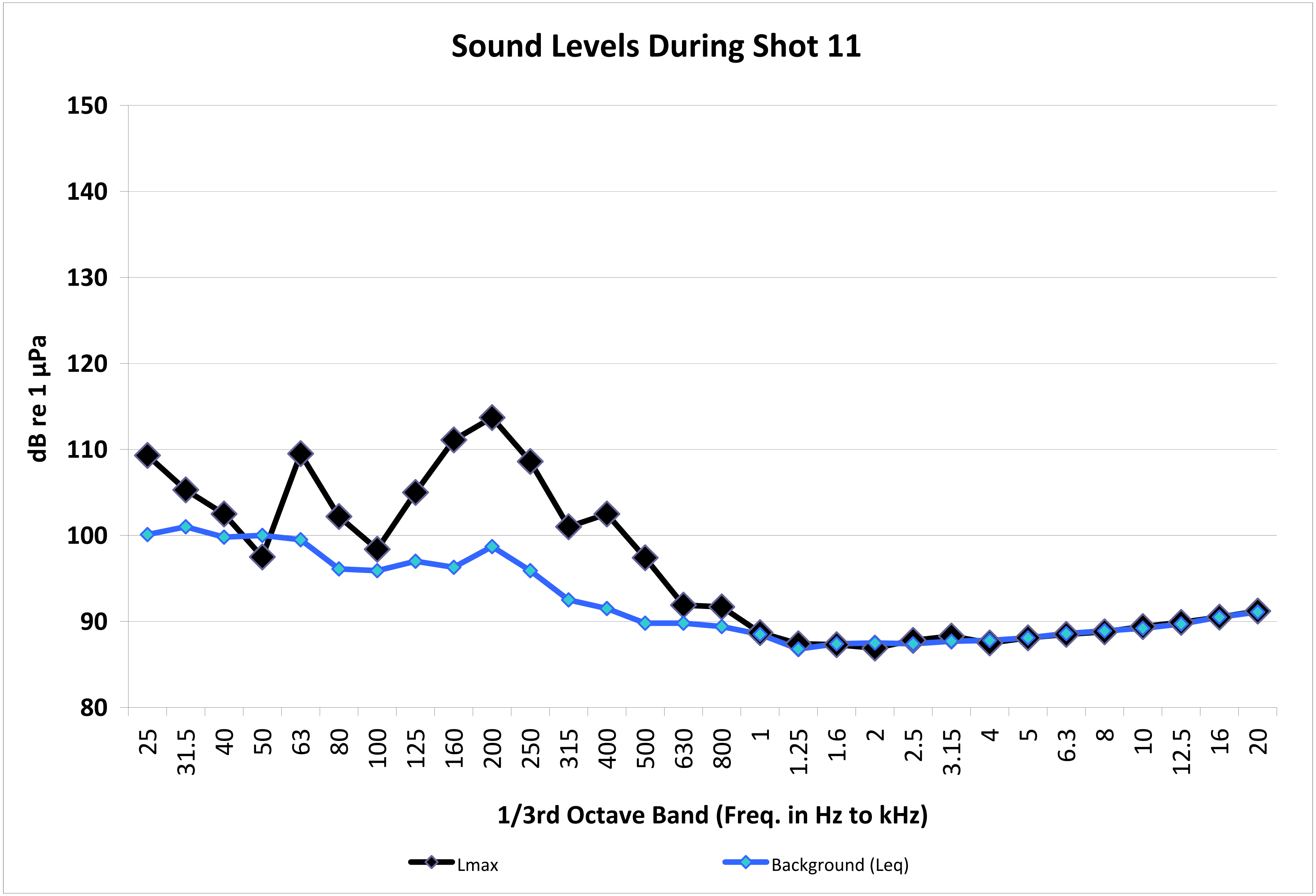


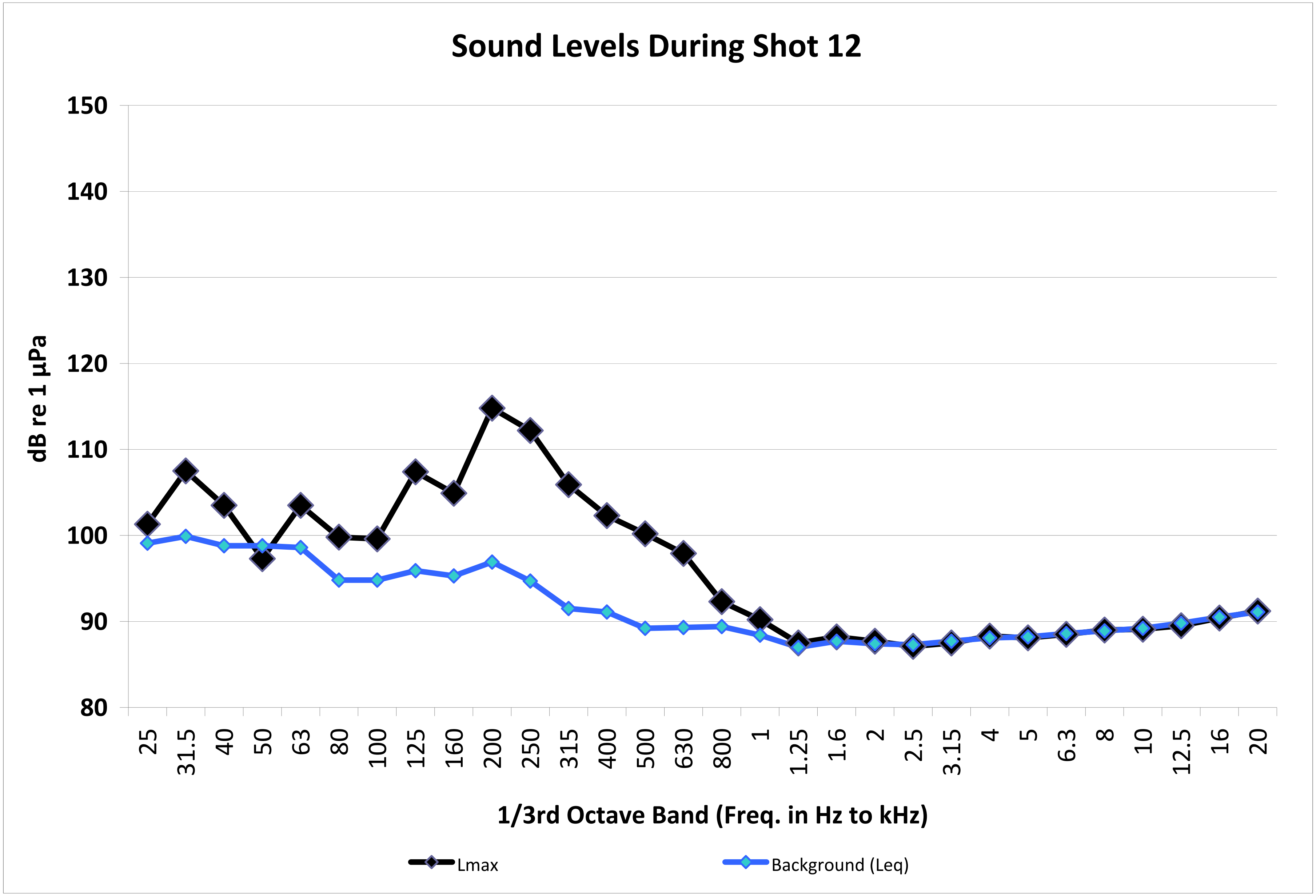
Sound Levels During Shot 8
dB re 1 µPa
150
140
130
120
110
100
90
80
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)


Sound Levels During Shot 9
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)

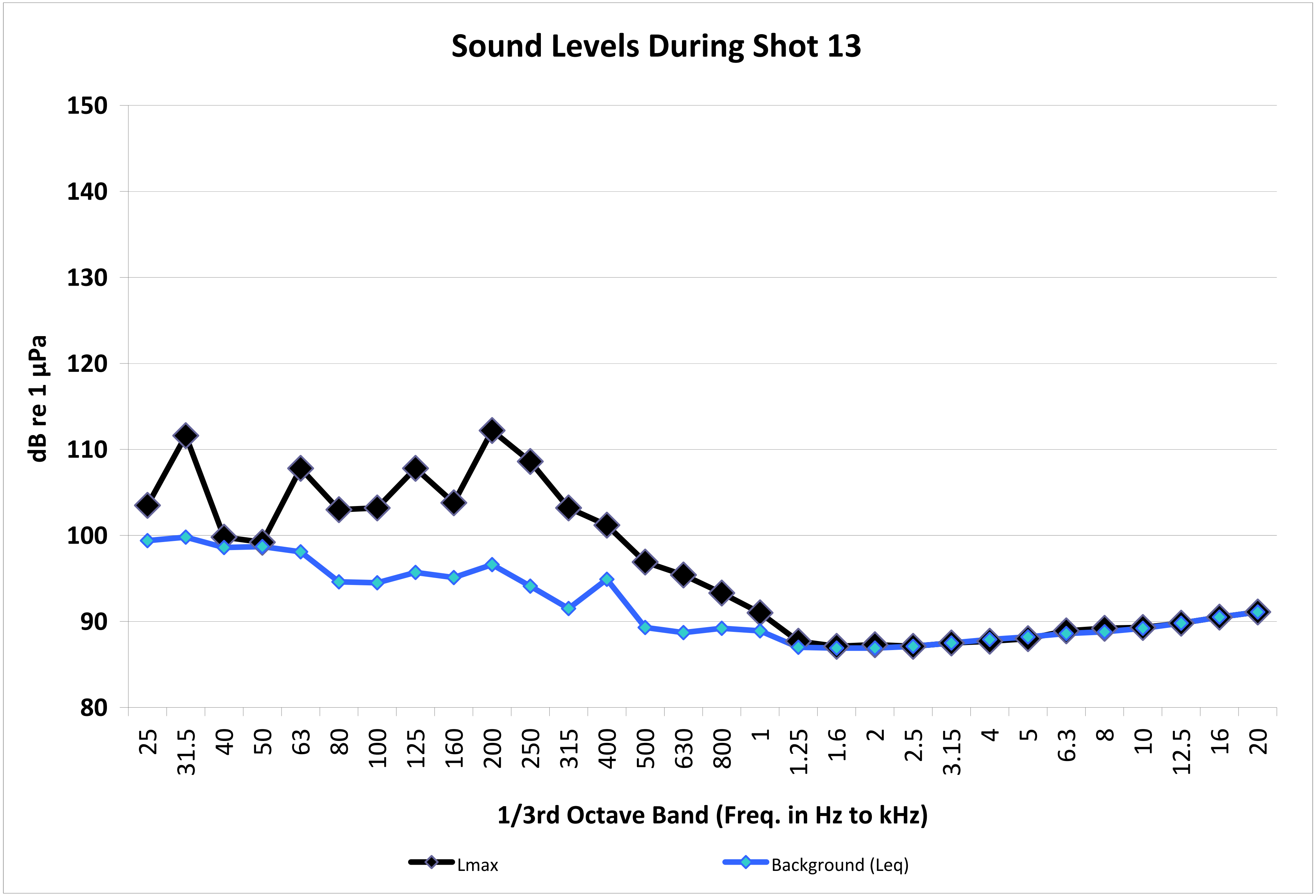


Sound Levels During Shot 10
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)

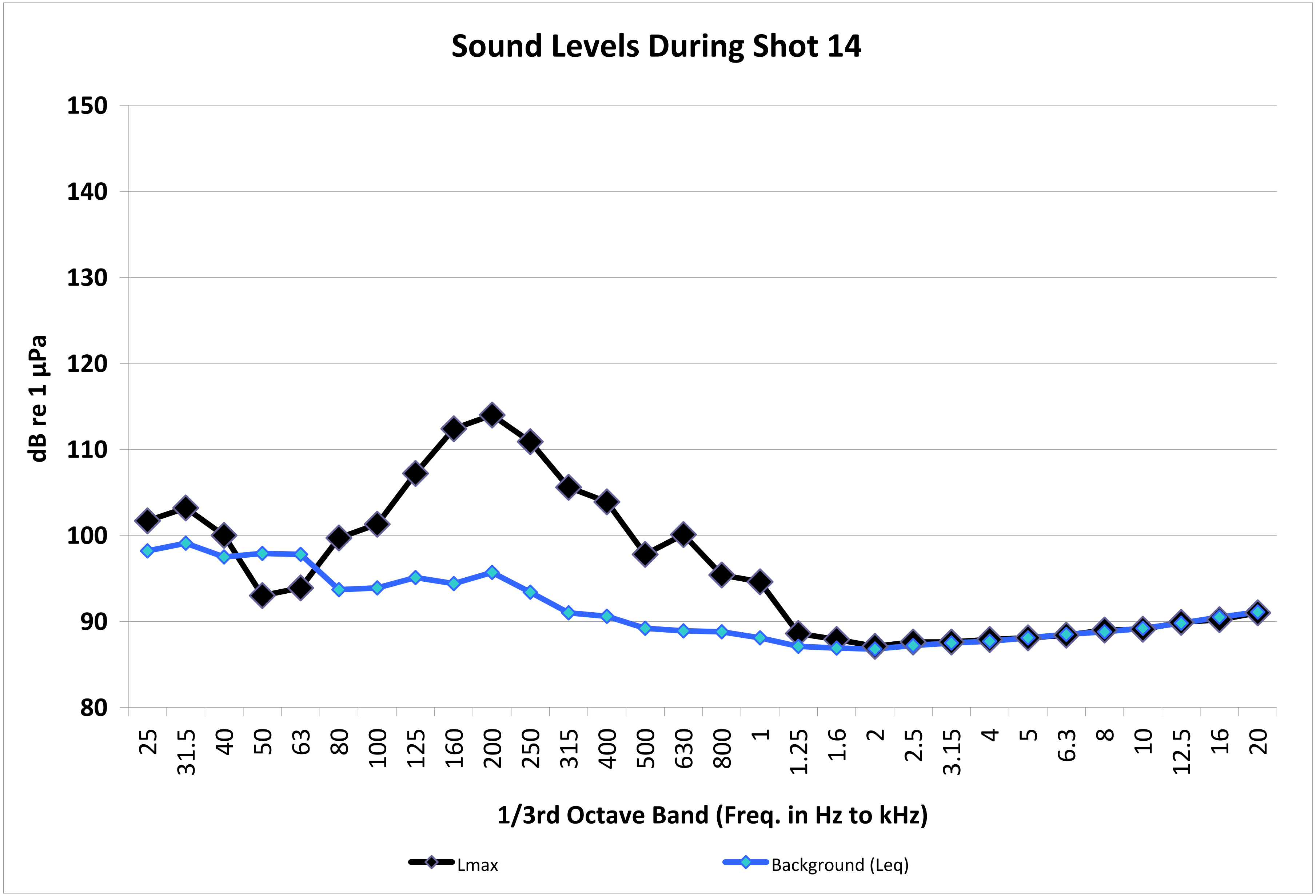

Sound Levels During Shot 11
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)



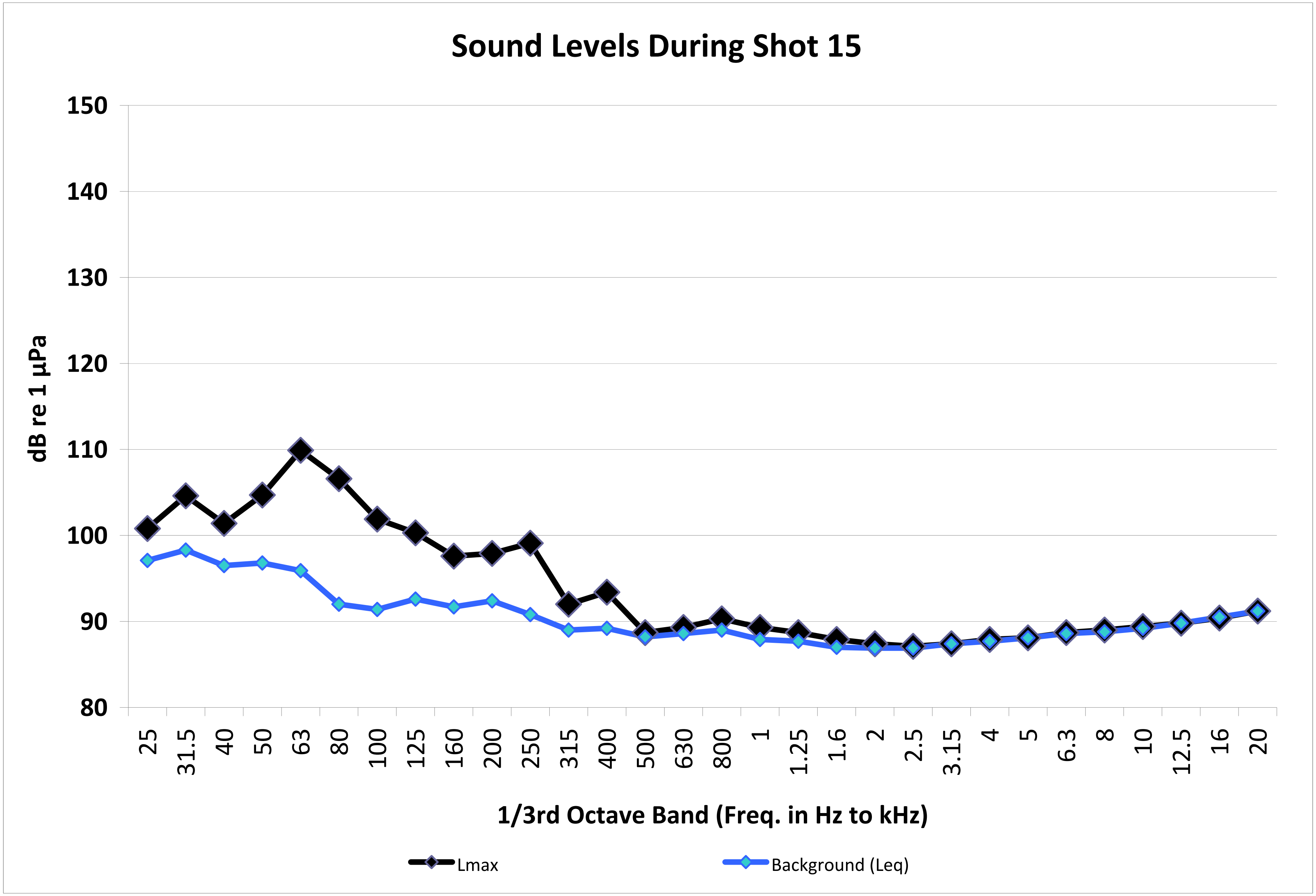
Sound Levels During Shot 12
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)

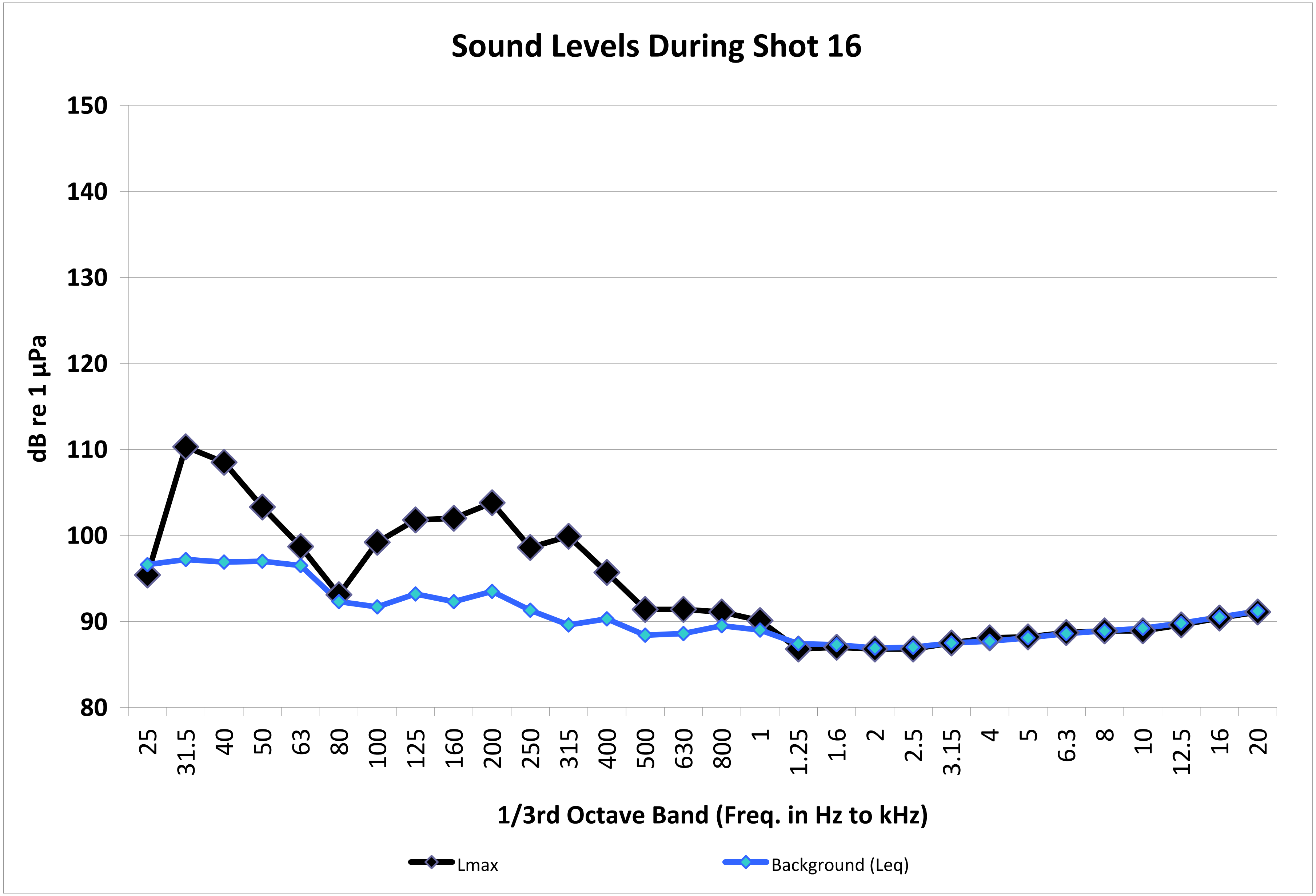


Sound Levels During Shot 13
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)

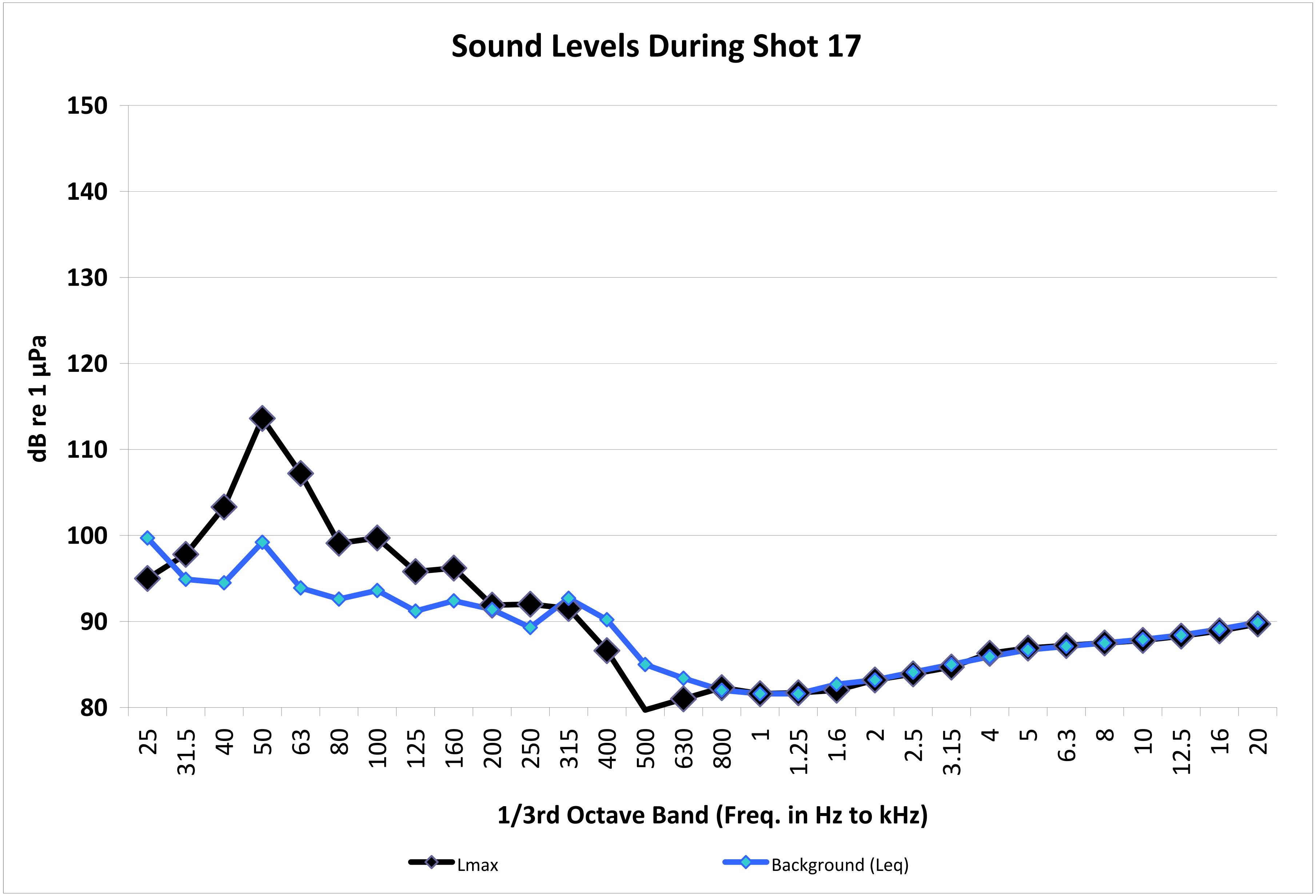


Sound Levels During Shot 14
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)


Sound Levels During Shot 15
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)



Sound Levels During Shot 16
150
140
130
120
110
100
90
80
dB re 1 µPa
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)



Sound Levels During Shot 17
dB re 1 µPa
150
140
130
120
110
100
90
80
25
31.5
40
50
63
80
100
125
160
200
250
315
400
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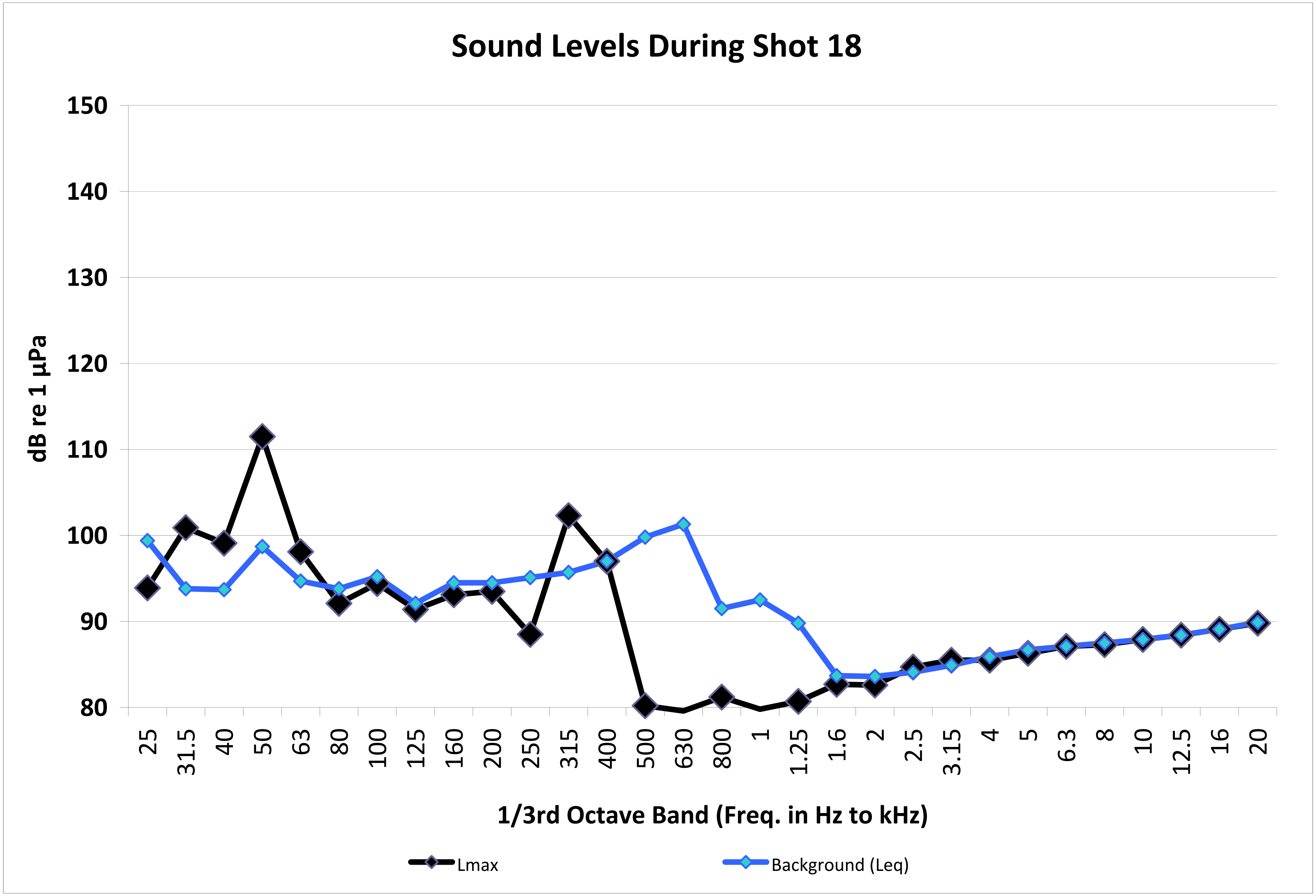
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)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160
200
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1.25
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12.5
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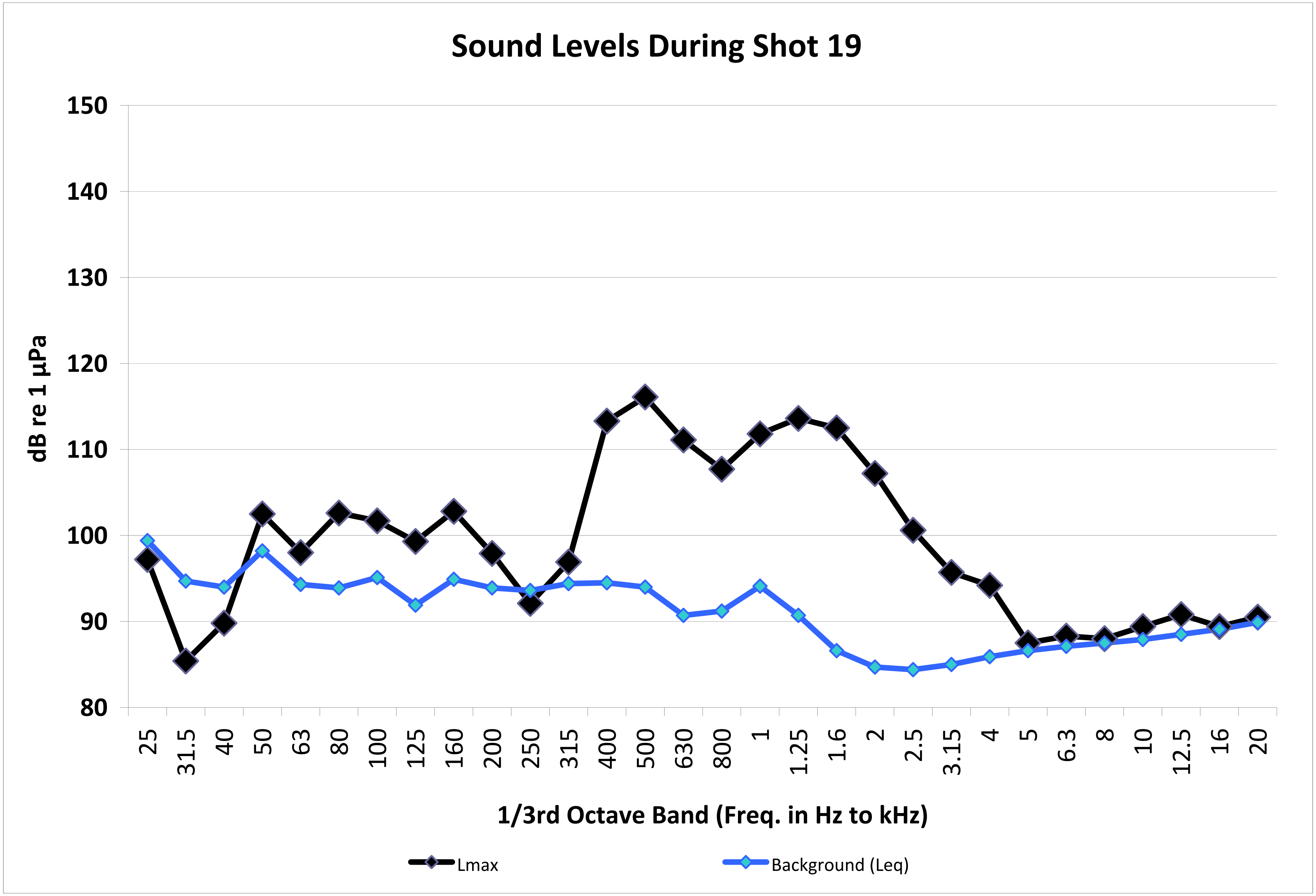
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)



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315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
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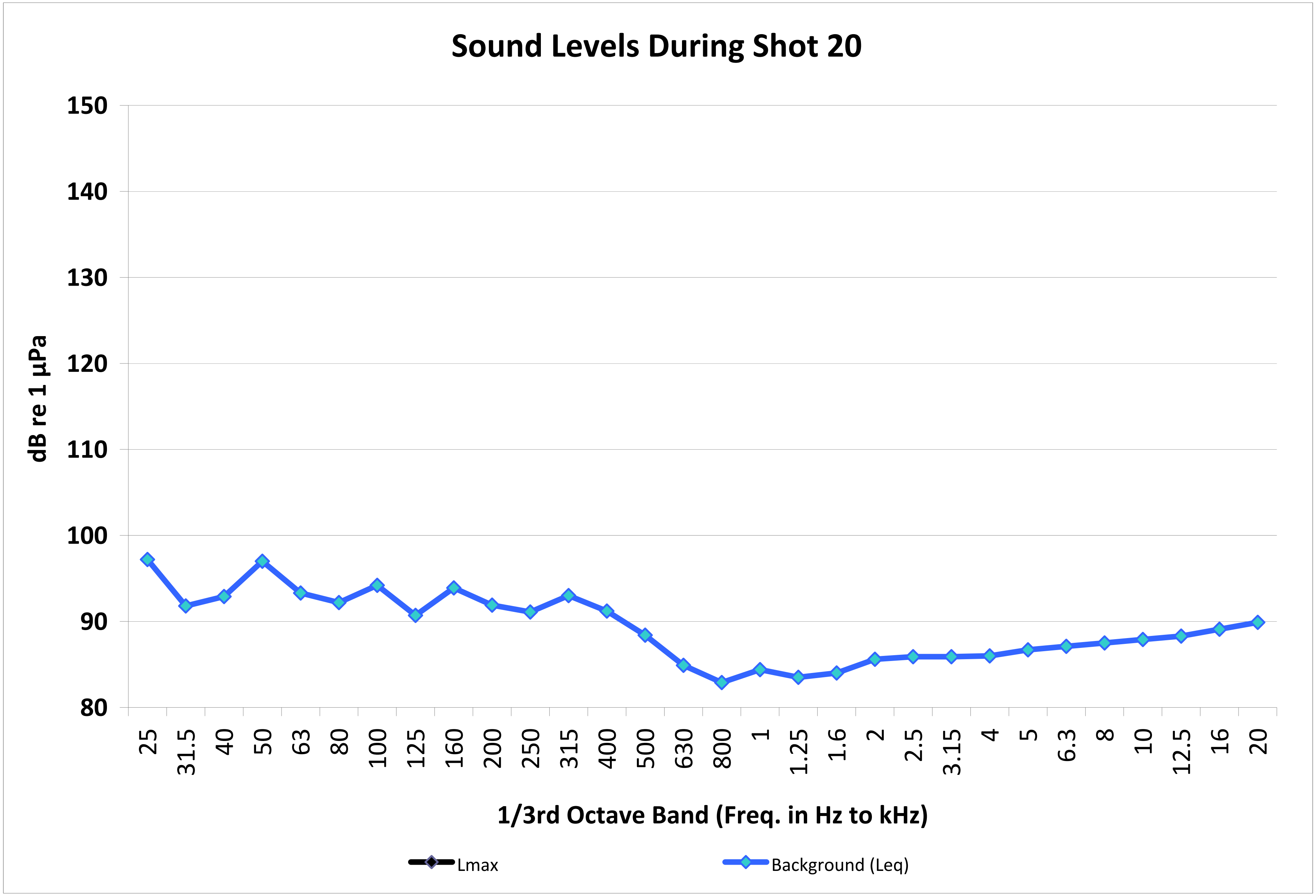
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)



Sound Levels During Shot 20
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dB re 1 µPa
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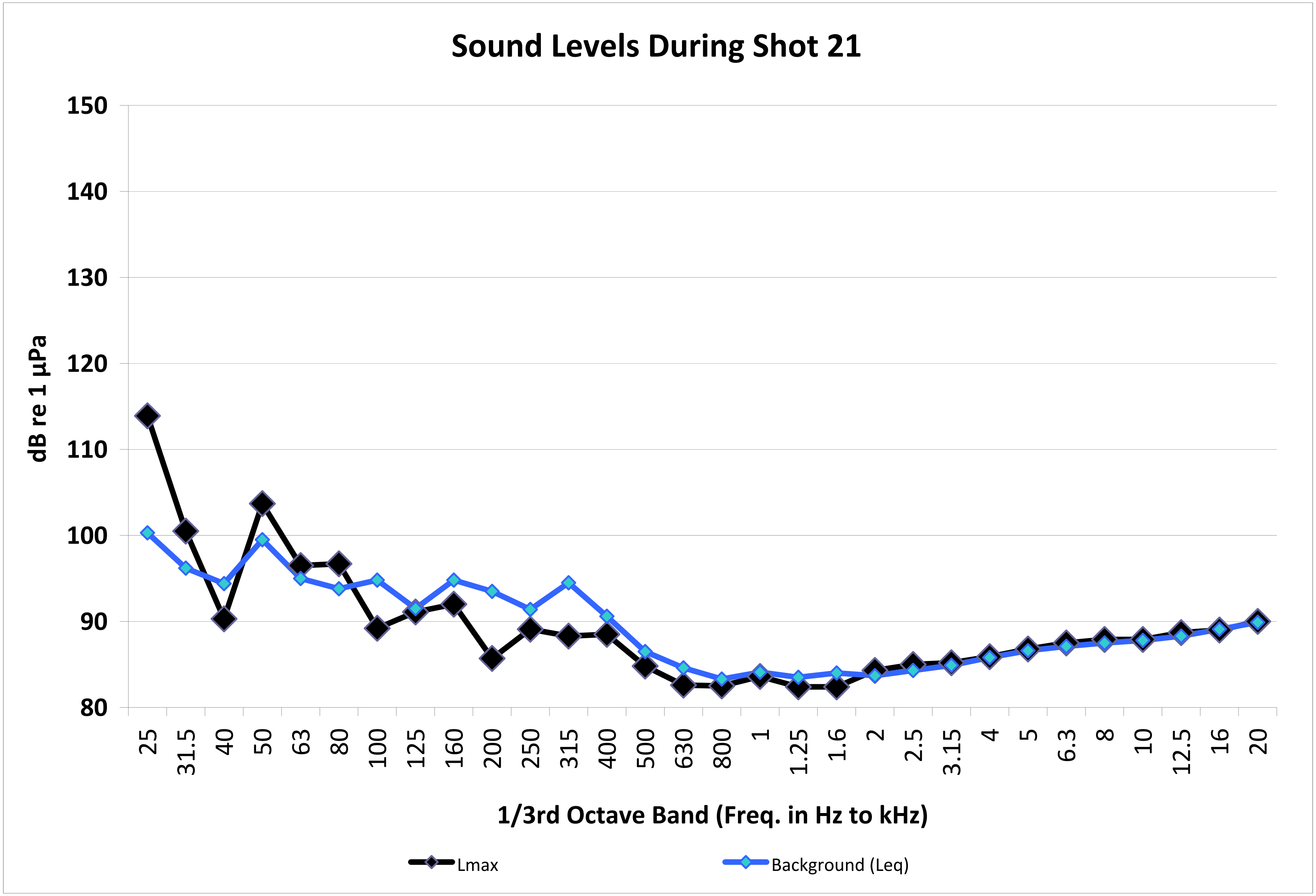
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)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dB re 1 µPa
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315
400
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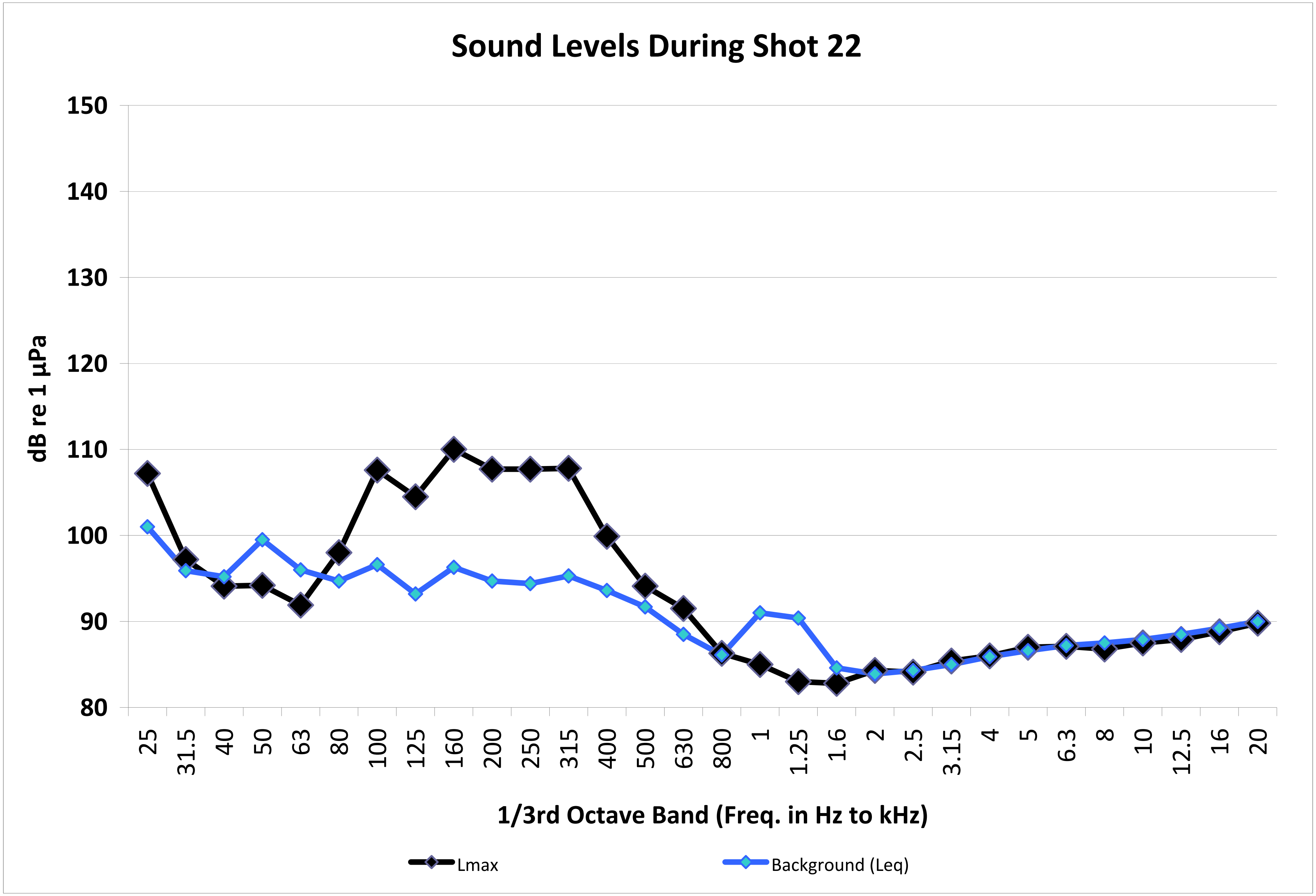
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)


Sound Levels During Shot 22
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120
110
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90
80
dB re 1 µPa
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31.5
40
50
63
80
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200
250
315
400
500
630
800
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
16
20
1/3rd Octave Band (Freq. in Hz to kHz)
Lmax
Background (Leq)

APPENDIX B

Sound Source Verification of Airguns 2012

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

Submitted to:
Fairweather LLC for
Apache Corporation

Authors:
Melanie Austin
Graham Warner

2013 January 4

P001134-006
Version 2.0

JASCO Applied Sciences
Suite 2305, 4464 Markham St.
Victoria, BC, V8Z 7X8, Canada
Phone: +1.250.483.3300
Fax: +1.250.483.3301
www.jasco.com

Suggested citation:

Austin, M.A., and G. Warner. 2012. *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.

Contents

Tables

Figures

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.

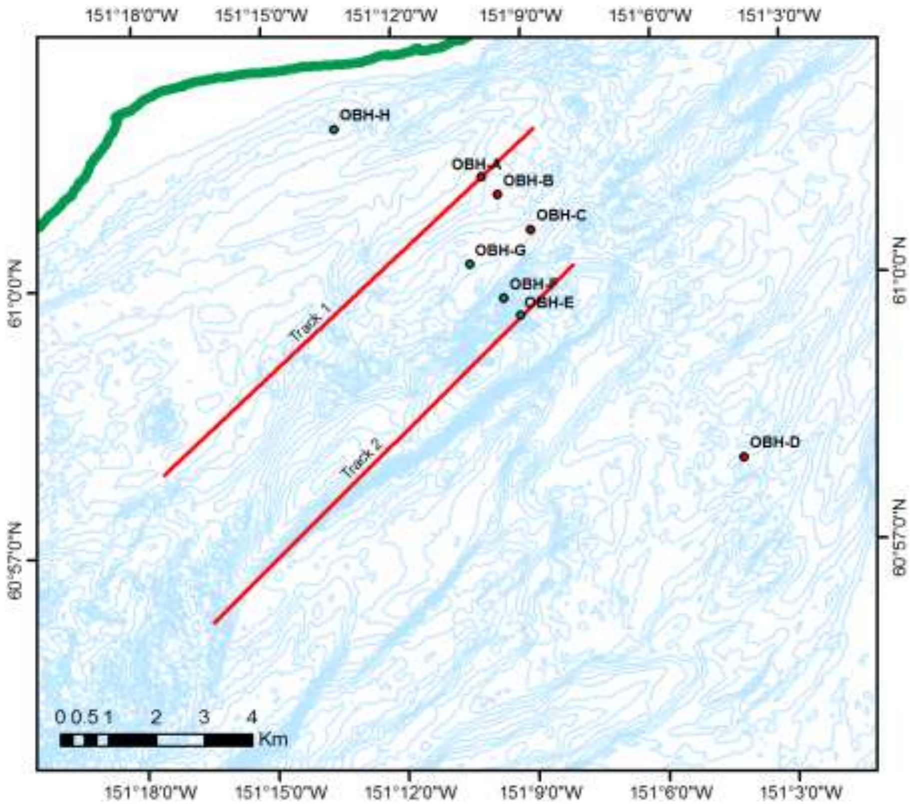


Figure 1. Map of the two acoustic survey lines and OBH locations.

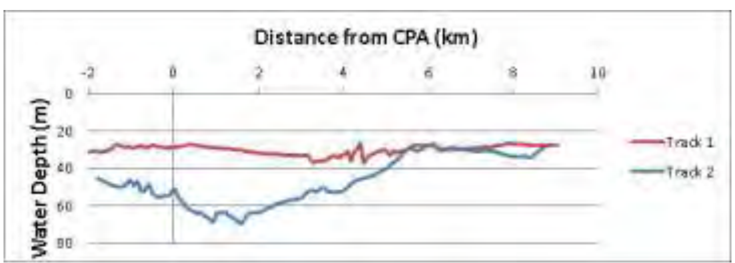


Figure 2: Water depth values along Track 2 measured during a single transit of the source vessel.

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.

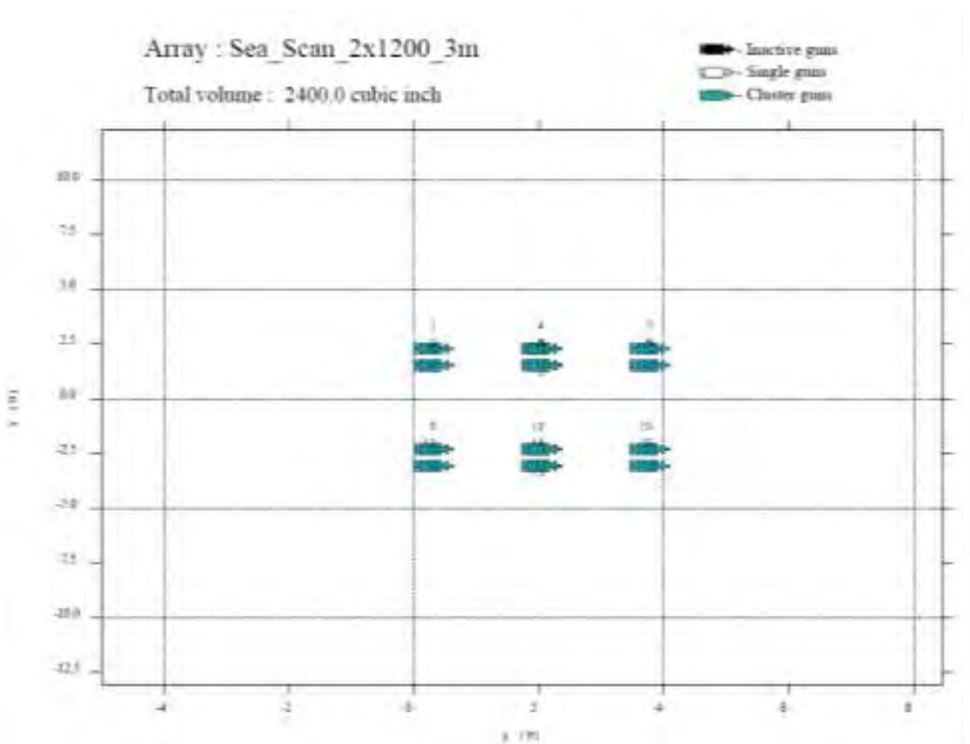


Figure 4. Geometry layout of 2400 in^3 array. Tow depth is 3.0 m; the volume of each airgun is indicated in cubic inches. This array consists of two 1200 in^3 sub-arrays separated horizontally by 4.6 m.

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 90th 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

4.1.1. Track 1

Peak SPL, 90% rms SPL and SEL for each shot along the nearshore line (Track 1) were computed from acoustic data recorded on OBH-A. 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 line. 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. 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. Table 4 lists ranges to several rms SPL thresholds for each of the fits in Figure 7. Figure 8 illustrates how rms pulse duration varied with range over the track line (left), with the rms SPL (right) for comparison. Figure 9 presents spectrograms of 10 in³ airgun pulses measured near CPA at 26 m and at 192 m. Figure 10 shows waveforms and SEL spectral density plots of these same pulses. A contour plot of 1/3-octave band levels versus range and frequency is shown in Figure 11. Sound levels near the source were highest between 40 and 50 Hz.

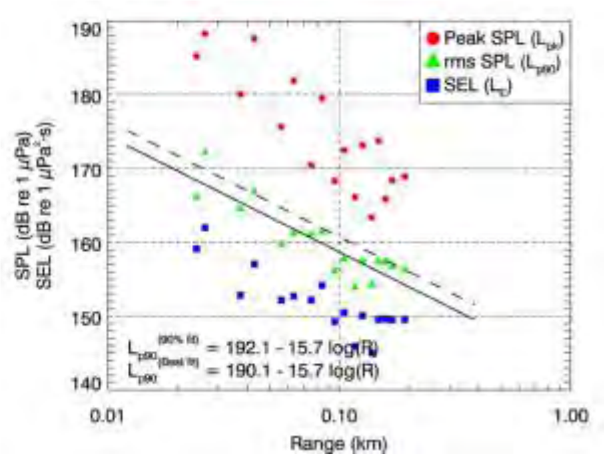


Figure 7: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 10 in^3 mitigation airgun pulses in the endfire direction for the nearshore track. Solid line is best fit of the empirical function to SPL_{rms90} values. Dashed line is the best-fit adjusted to exceed 90% of the SPL_{rms90}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

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

*Extrapolated beyond measurement range.

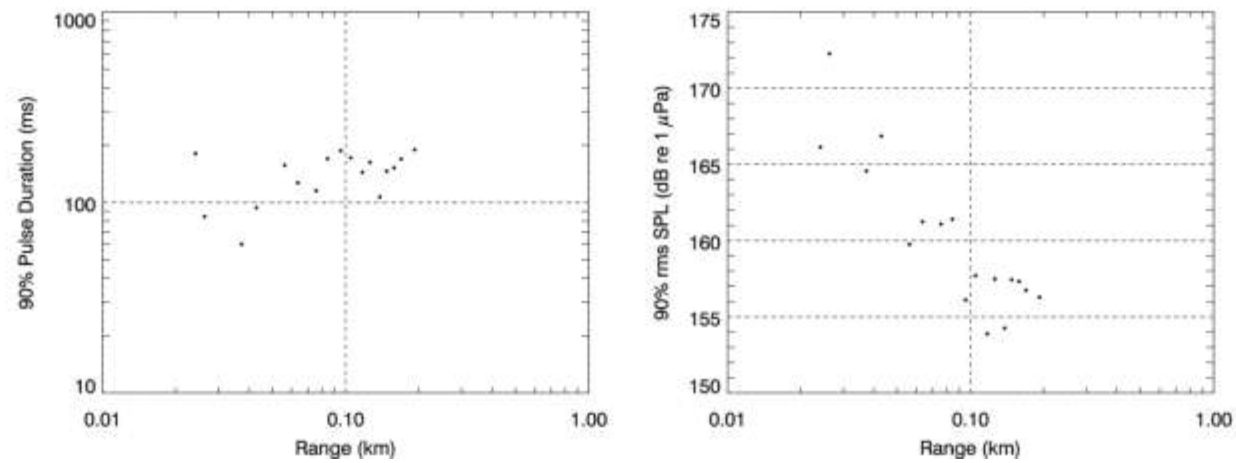


Figure 8. 10 in³ airgun array 90% pulse duration (left) and rms SPL (right) as a function of range at the nearshore site.

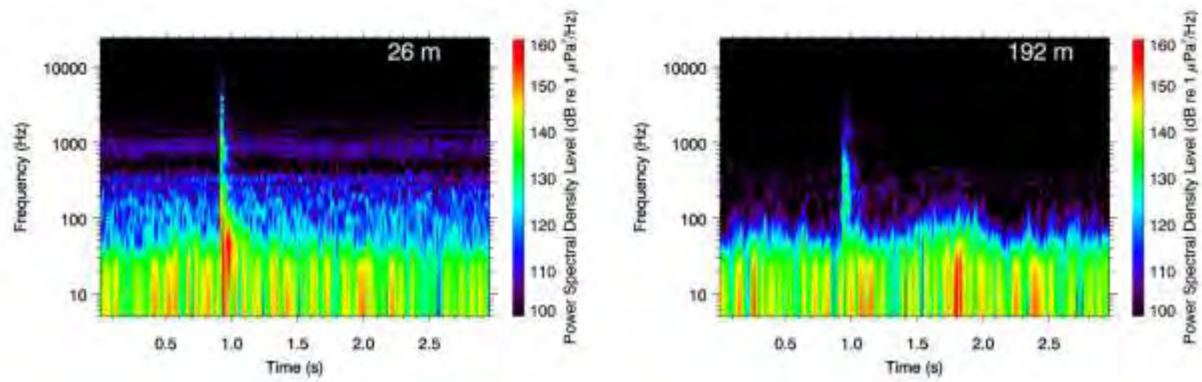


Figure 9. Spectrograms of airgun pulses from the 10 in³ airgun array at two distances in the endfire direction at the nearshore site. 2048-pt FFT, 48 kHz sample rate, Hanning window.

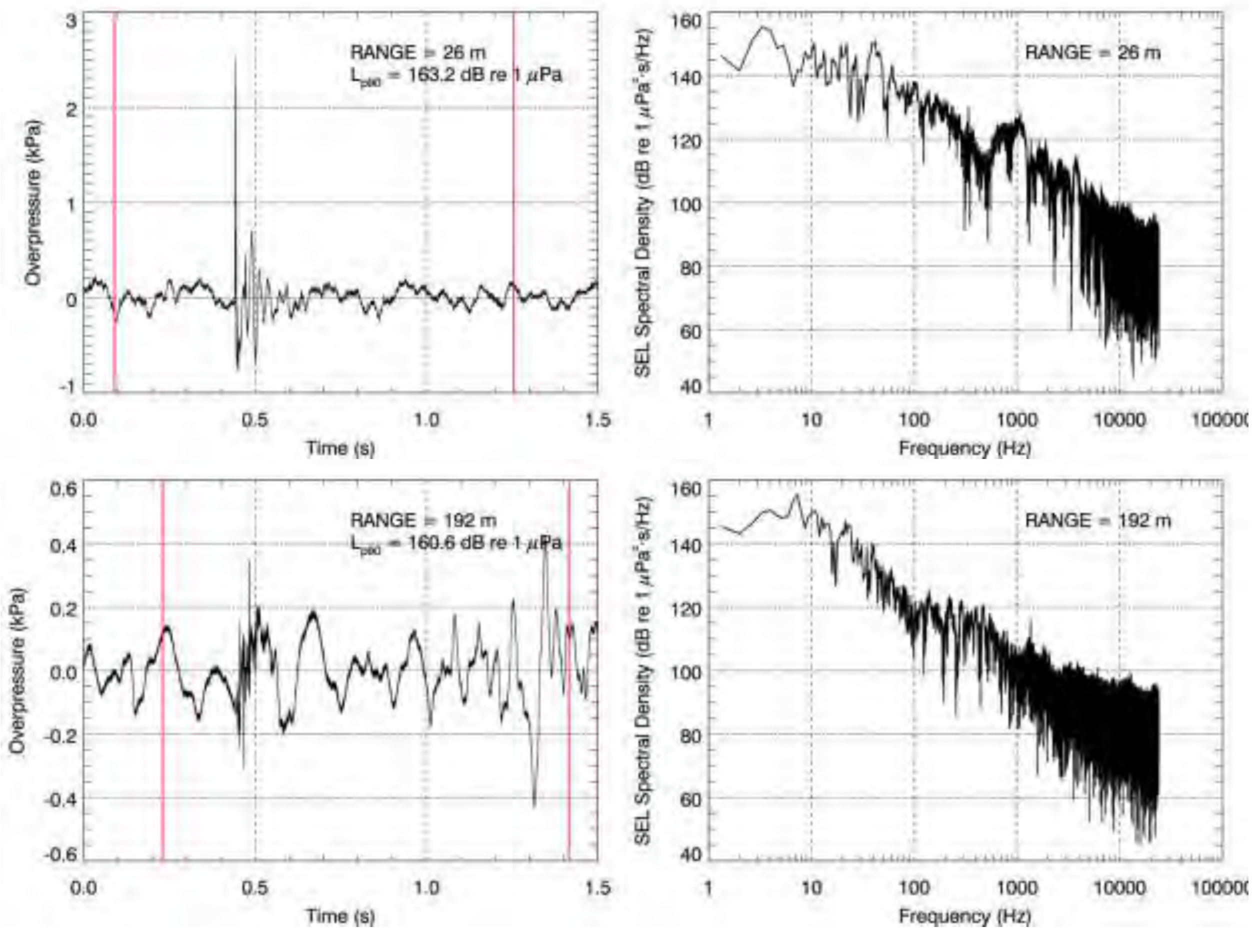


Figure 10. Waveform (left) and corresponding SEL spectral density (right) plots of 10 in³ airgun array pulses at two distances in the endfire direction at the nearshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.

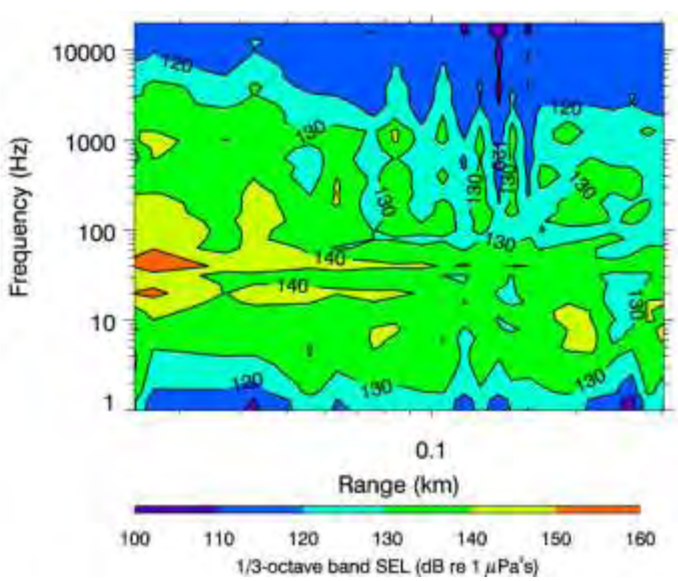


Figure 11. 1/3 octave band SEL levels as a function of range and frequency for the 10 in³ airgun array in the endfire direction at the nearshore site.

4.1.2. Track 2

Peak SPL, 90% rms SPL and SEL for each shot along the offshore line (Track 2) were computed from acoustic data recorded on OBH-E. Figure 12 shows sound levels from the 10 in³ mitigation gun versus slant range measured in the endfire direction on OBH-E as the source transited the line. 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. Table 5 lists ranges to several rms SPL thresholds for each of the fits in Figure 12. Figure 13 illustrates how rms pulse duration varied with range over the track line (left), with the rms SPL (right) for comparison. Figure 14 presents spectrograms of 10 in³ airgun pulses measured near CPA at 18 m and at 493 m, 1522 m, and 4993 m. Figure 15 shows waveforms and SEL spectral density plots of these same pulses. A contour plot of 1/3-octave band levels versus range and frequency is shown in Figure 16. Sound levels near the source were highest between 70 and 150 Hz.

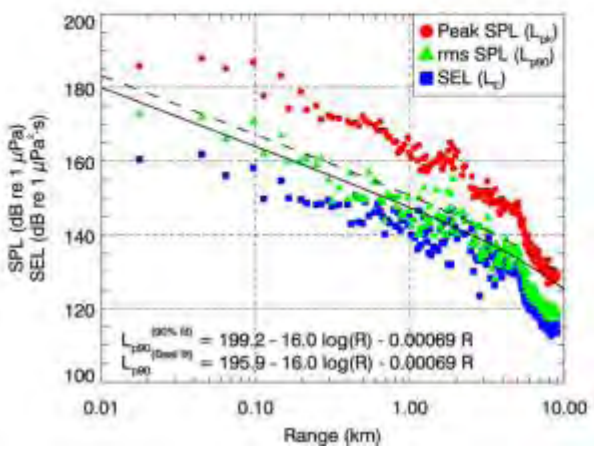


Figure 12: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 10 in^3 mitigation airgun pulses in the endfire direction for the offshore track. Solid line is best fit of the empirical function to SPL_{rms90} values. Dashed line is the best-fit adjusted to exceed 90% of the SPL_{rms90} values.

Table 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 12.

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

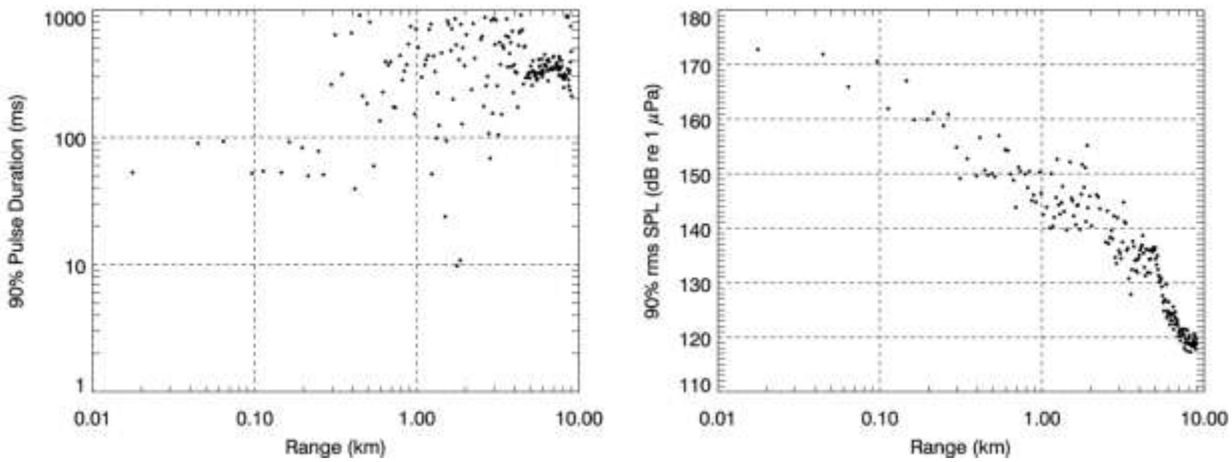


Figure 13. 10 in³ airgun array 90% pulse duration (left) and rms SPL (right) as a function of range at the offshore site.

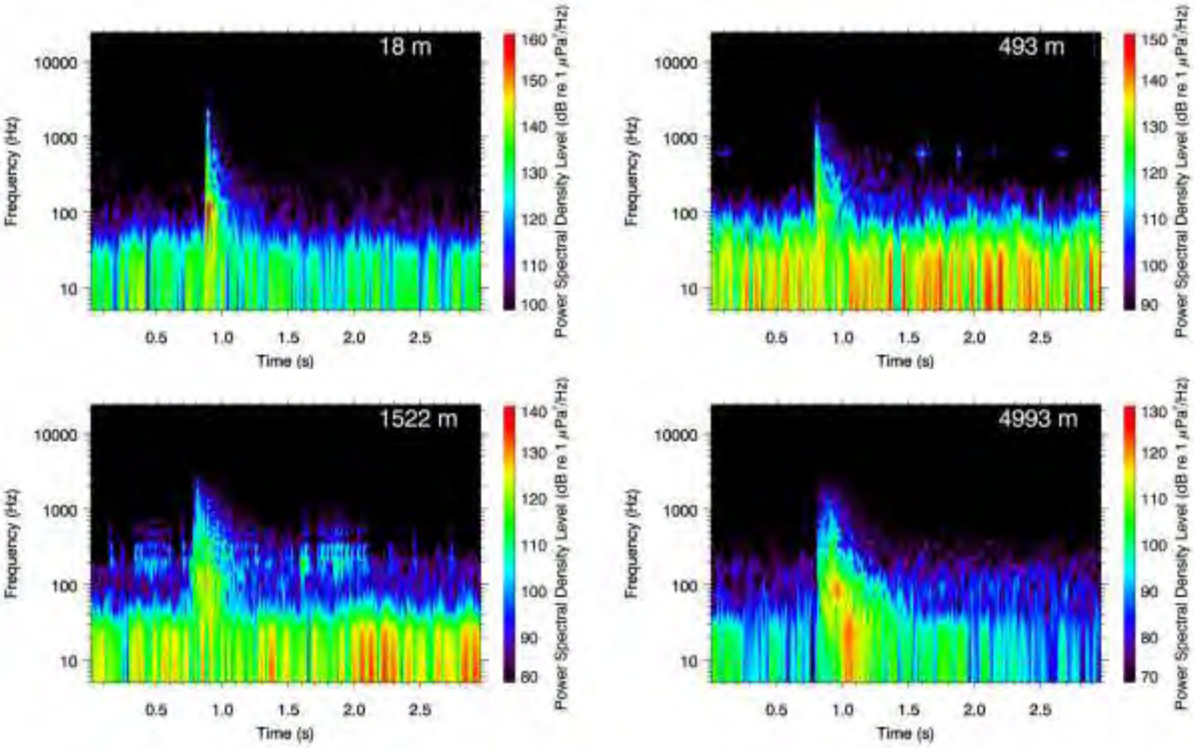
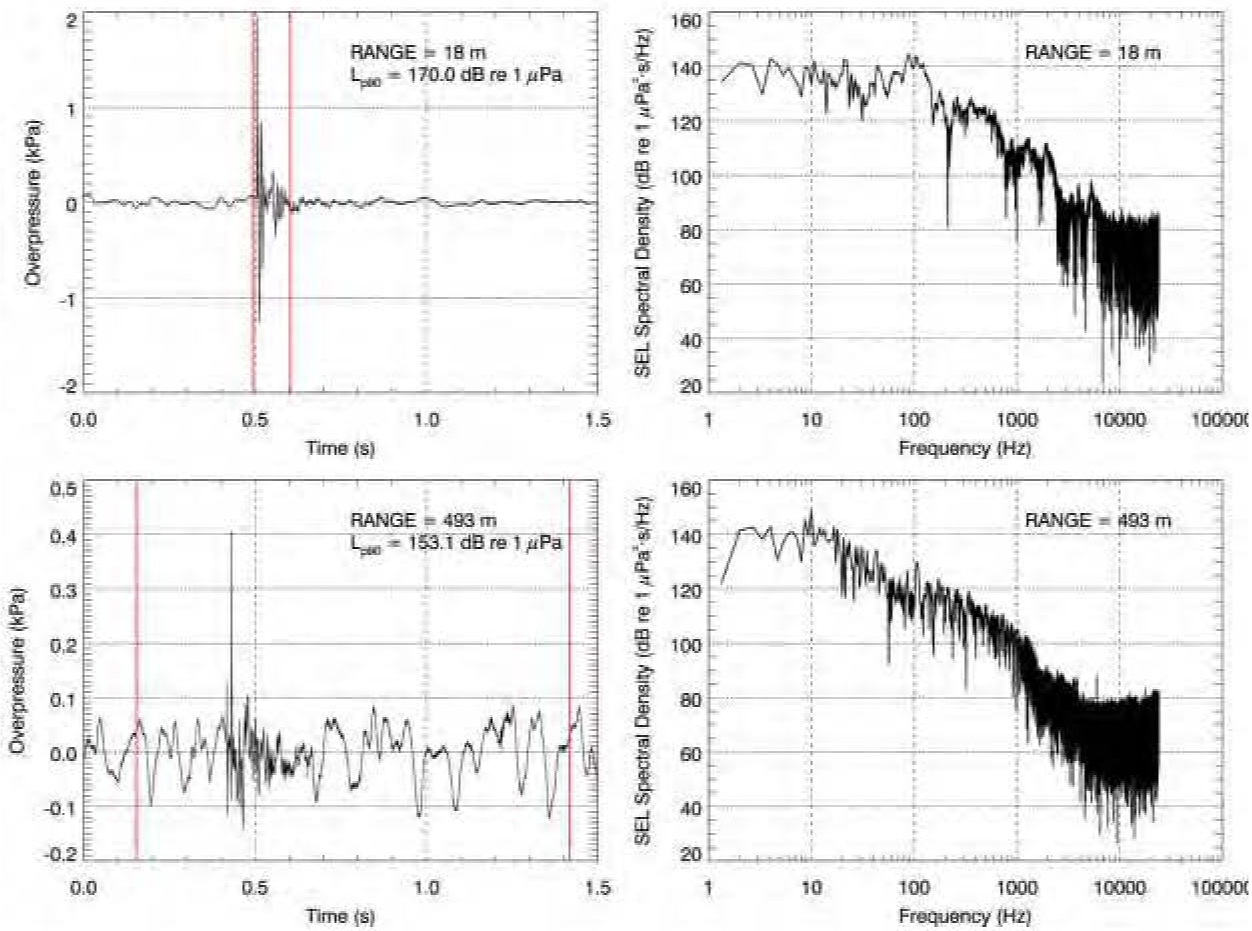


Figure 14. Spectrograms of airgun pulses from the 10 in³ airgun array at various distances in the endfire direction at the offshore site. 4096-pt FFT, 96 kHz sample rate, Hanning window.


RANGE = 18 m
L_{pk0} = 170.0 dB re 1 µPa
Overpressure (kPa)
Time (s)
RANGE = 18 m
SEL Spectral Density (dB re 1 µPa²·s/Hz)
Frequency (Hz)
RANGE = 493 m
L_{pk0} = 153.1 dB re 1 µPa
Overpressure (kPa)
Time (s)
RANGE = 493 m
SEL Spectral Density (dB re 1 µPa²·s/Hz)
Frequency (Hz)

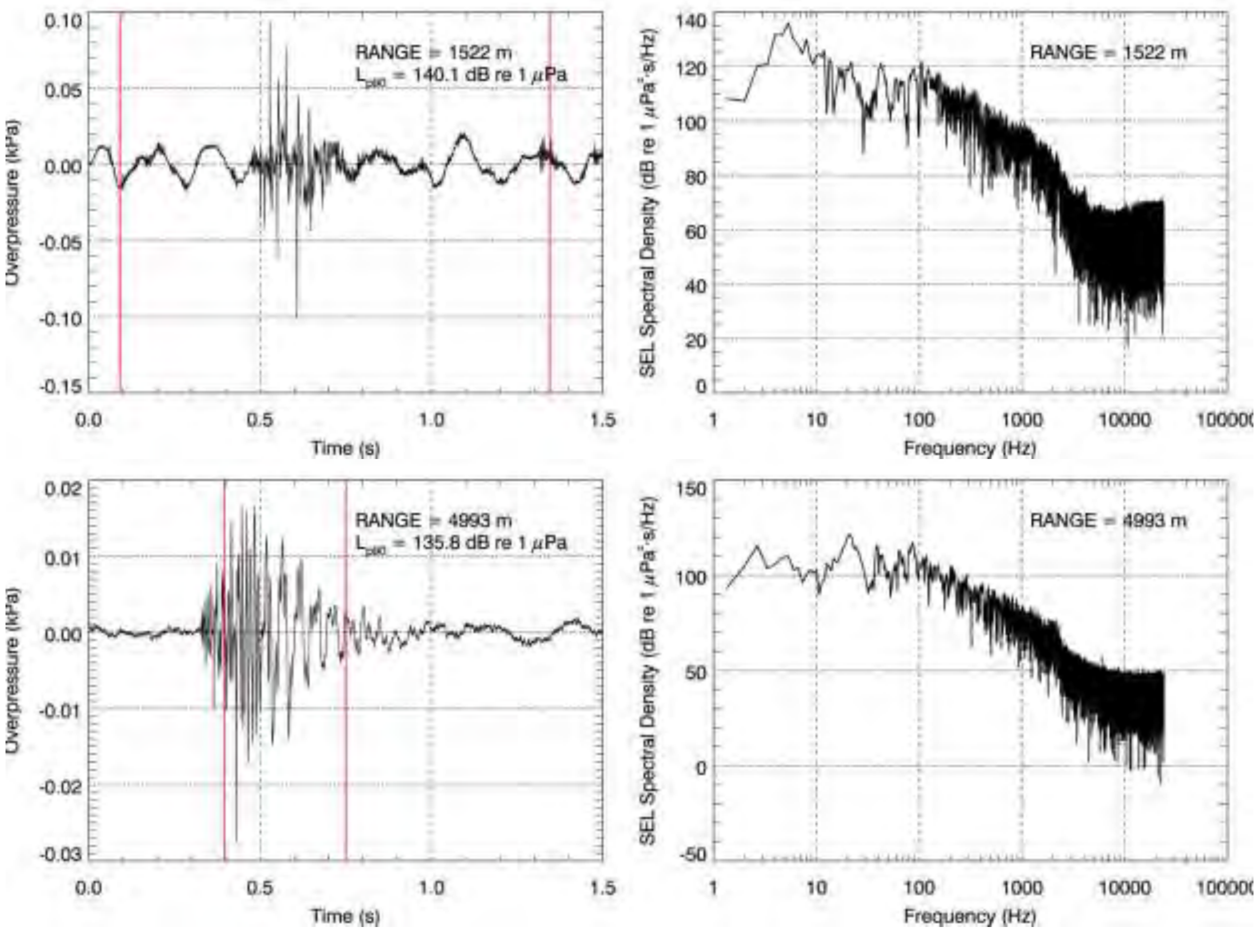


Figure 15. Waveform (left) and corresponding SEL spectral density (right) plots of 10 in³ airgun array pulses at various distances in the endfire direction at the offshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.

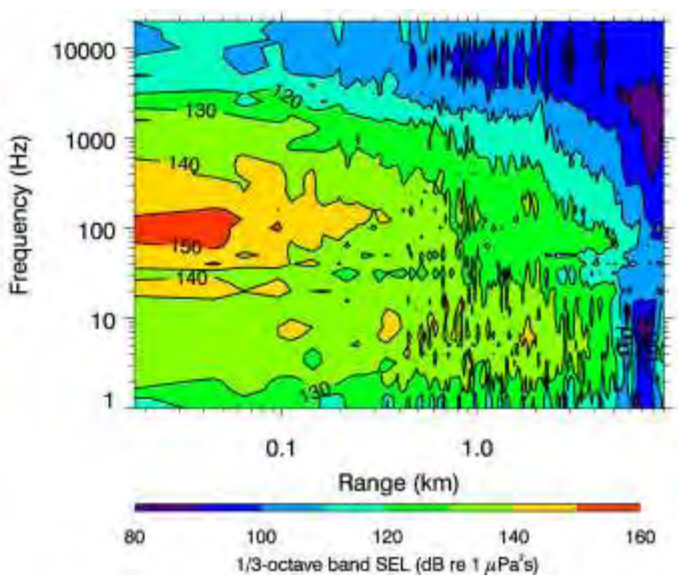


Figure 16. 1/3 octave band SEL levels as a function of range and frequency for the 10 in³ airgun array in the endfire direction at the offshore site.

4.2. 440 in^3 Airgun Array

4.2.1. Track 1

Peak SPL, 90% rms SPL and SEL for each shot along the nearshore line (Track 1) were computed from acoustic data recorded on OBHs A-D. Figure 17 shows sound levels from the 440 in³ airgun array versus slant range measured in the endfire and broadside directions. 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 prior to SPL calculations to isolate airgun sounds from flow noise. Table 6 lists ranges to several rms SPL thresholds for each of the fits in Figure 17. Figures Figure 18 and Figure 19 illustrate how rms pulse duration varied with range in the endfire and broadside directions, with the rms SPL for comparison. Figure 20 presents spectrograms of 440 in³ airgun array pulses in the endfire direction at 471 m, 1537 m, and 7934 m. Pulses in the broadside direction near CPA at 22 m, 477 m, 1524 m, and 7936 m are shown in Figure 21. Figures Figure 22 and Figure 23 show waveforms and SEL spectral density plots of these same endfire and broadside pulses, respectively. Contour plots of 1/3-octave band levels versus range and frequency are shown in Figure 24. Sound levels near the source were highest between 30 and 300 Hz in the endfire direction and between 20 and 300 Hz in the broadside direction.

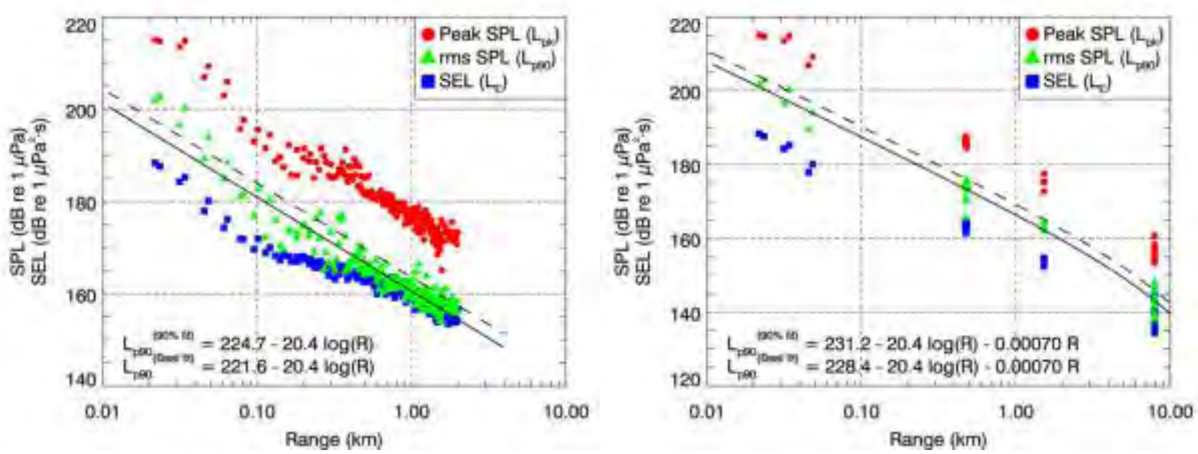


Figure 17: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 440 in^3 airgun array pulses in the endfire (left) and broadside (right) directions measured for the nearshore line (Track 1). Solid line is best fit of the empirical function to SPL_{rms90} values. Dashed line is the best-fit adjusted to exceed 90% of the SPL_{rms90} values.

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 17.

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

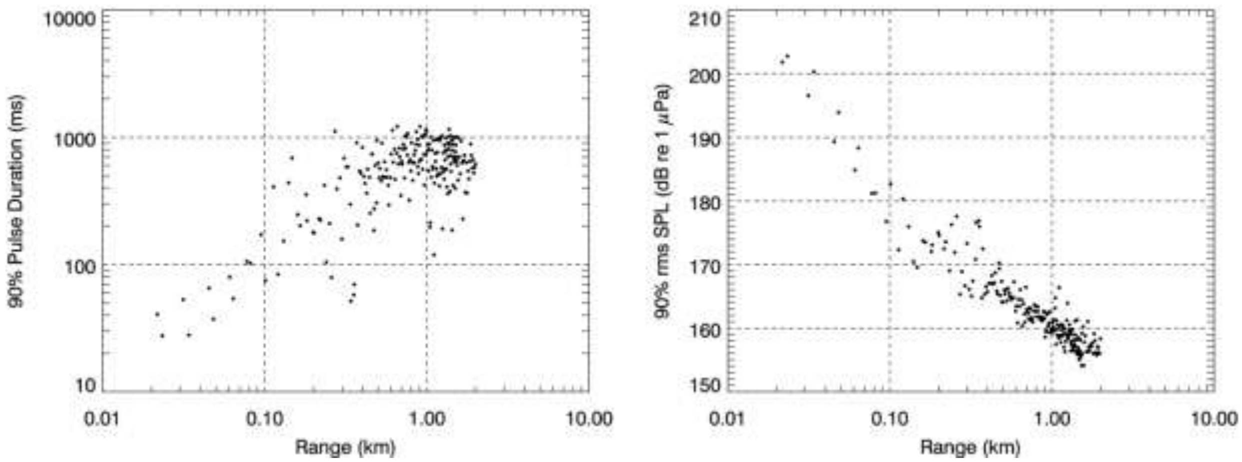


Figure 18. 440 in³ airgun array 90% pulse duration (left) and rms SPL (right) in the endfire direction as a function of range at the nearshore site.

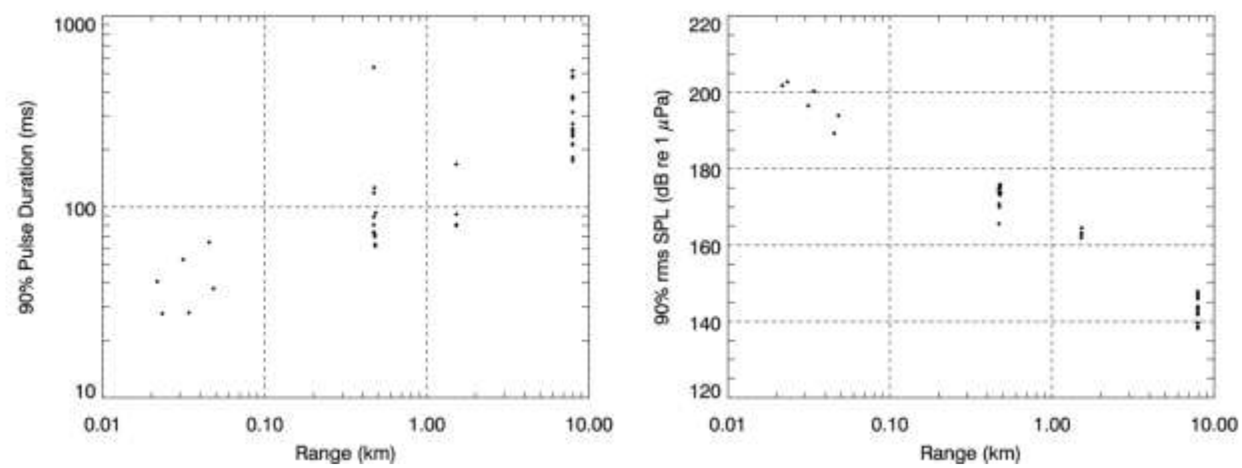


Figure 19. 440 in³ airgun array 90% pulse duration (left) and rms SPL (right) in the broadside direction as a function of range at the nearshore site.

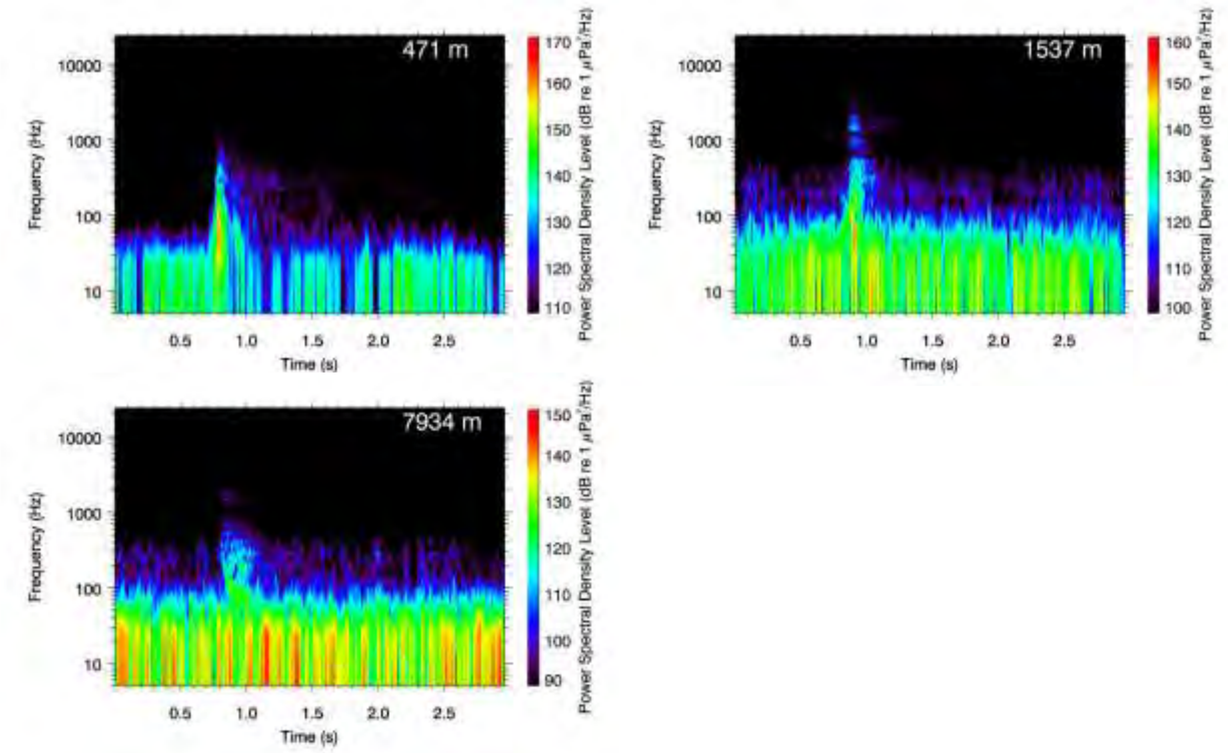


Figure 20. Spectrograms of airgun pulses from the 440 in³ airgun array at various distances in the endfire direction at the nearshore site. 2048-pt FFT, 48 kHz sample rate, Hanning window.

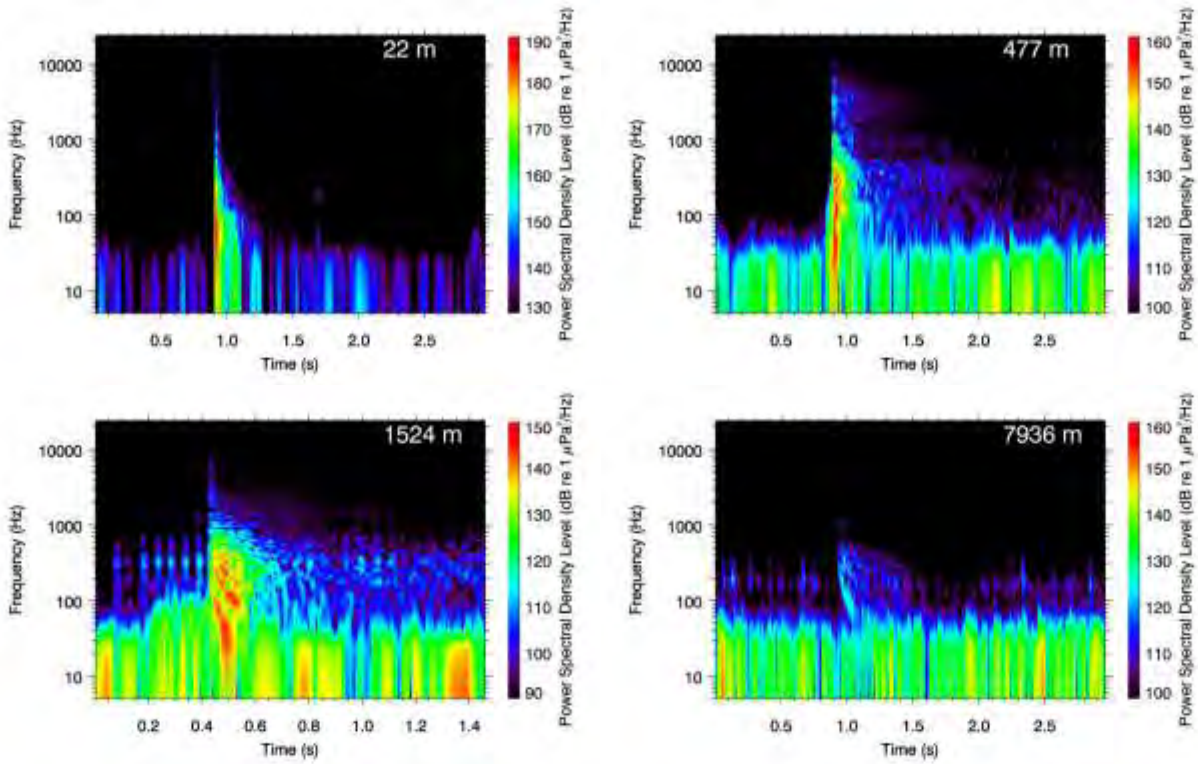


Figure 21. Spectrograms of airgun pulses from the 440 in³ airgun array at various distances in the broadside direction at the nearshore site. 2048-pt FFT, 48 kHz sample rate, Hanning window.

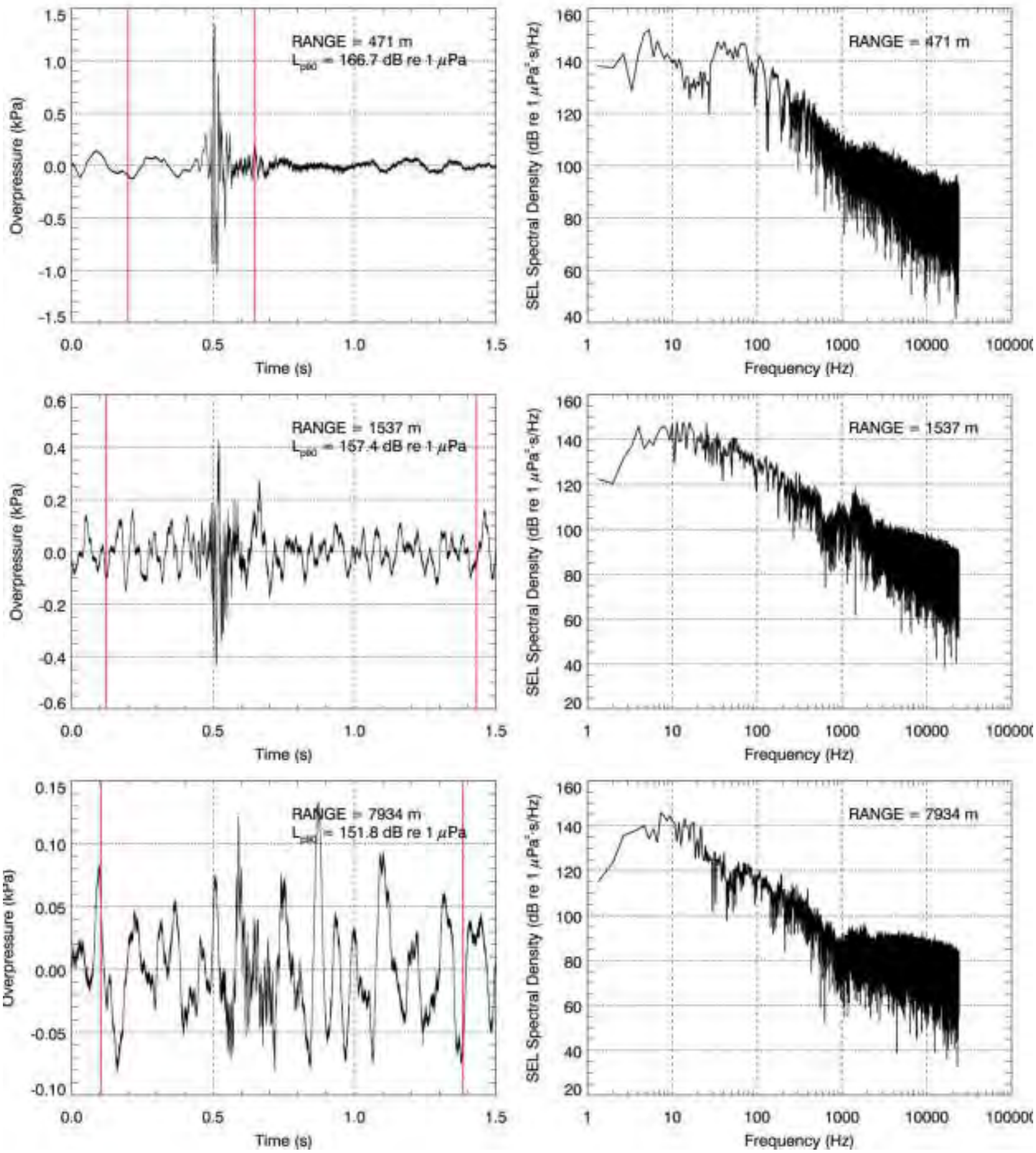
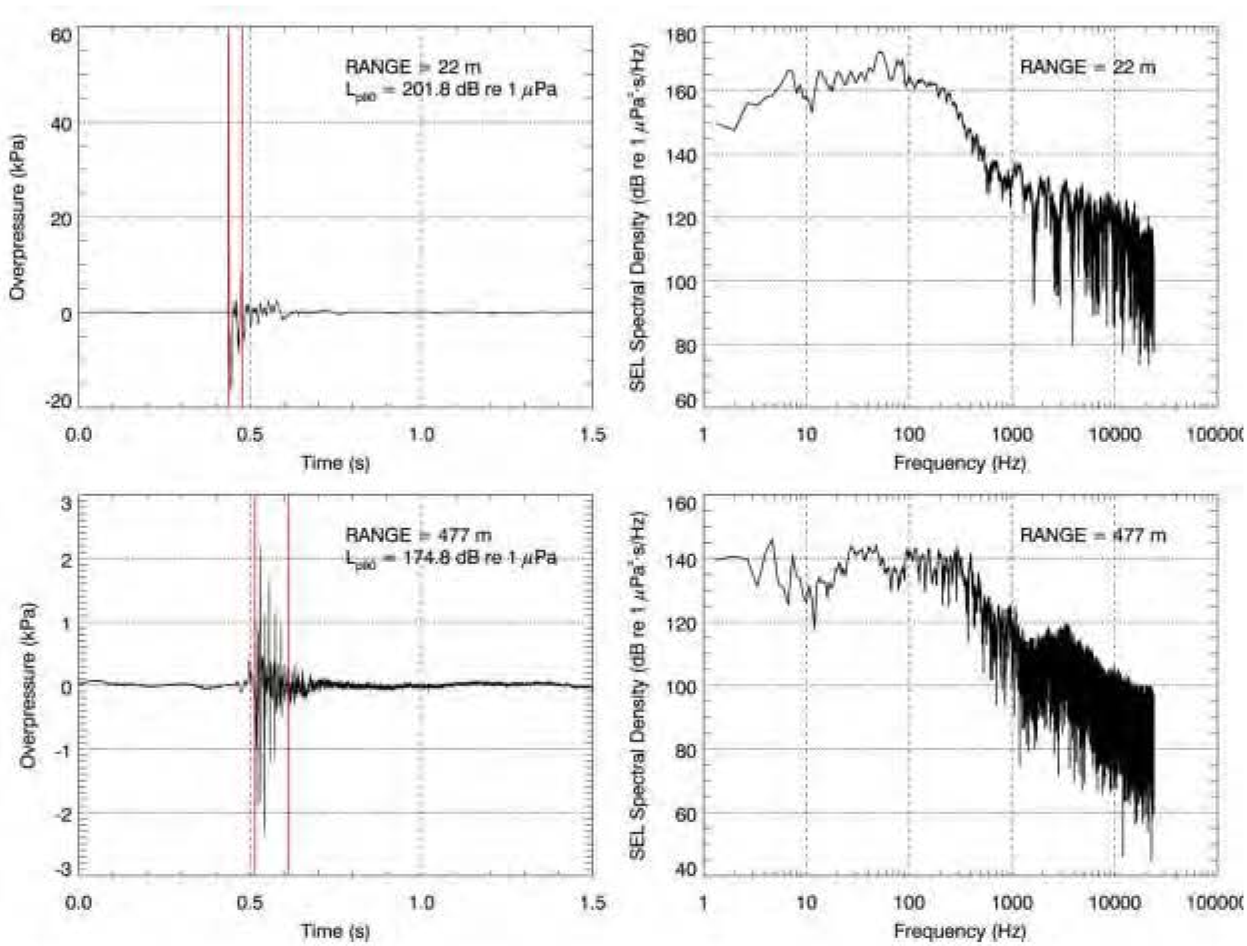


Figure 22. Waveform (left) and corresponding SEL spectral density (right) plots of 440 in³ airgun array pulses at various distances in the endfire direction at the nearshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.


RANGE = 22 m
L_{pk0} = 201.8 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 22 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)
RANGE = 477 m
L_{pk0} = 174.8 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 477 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)

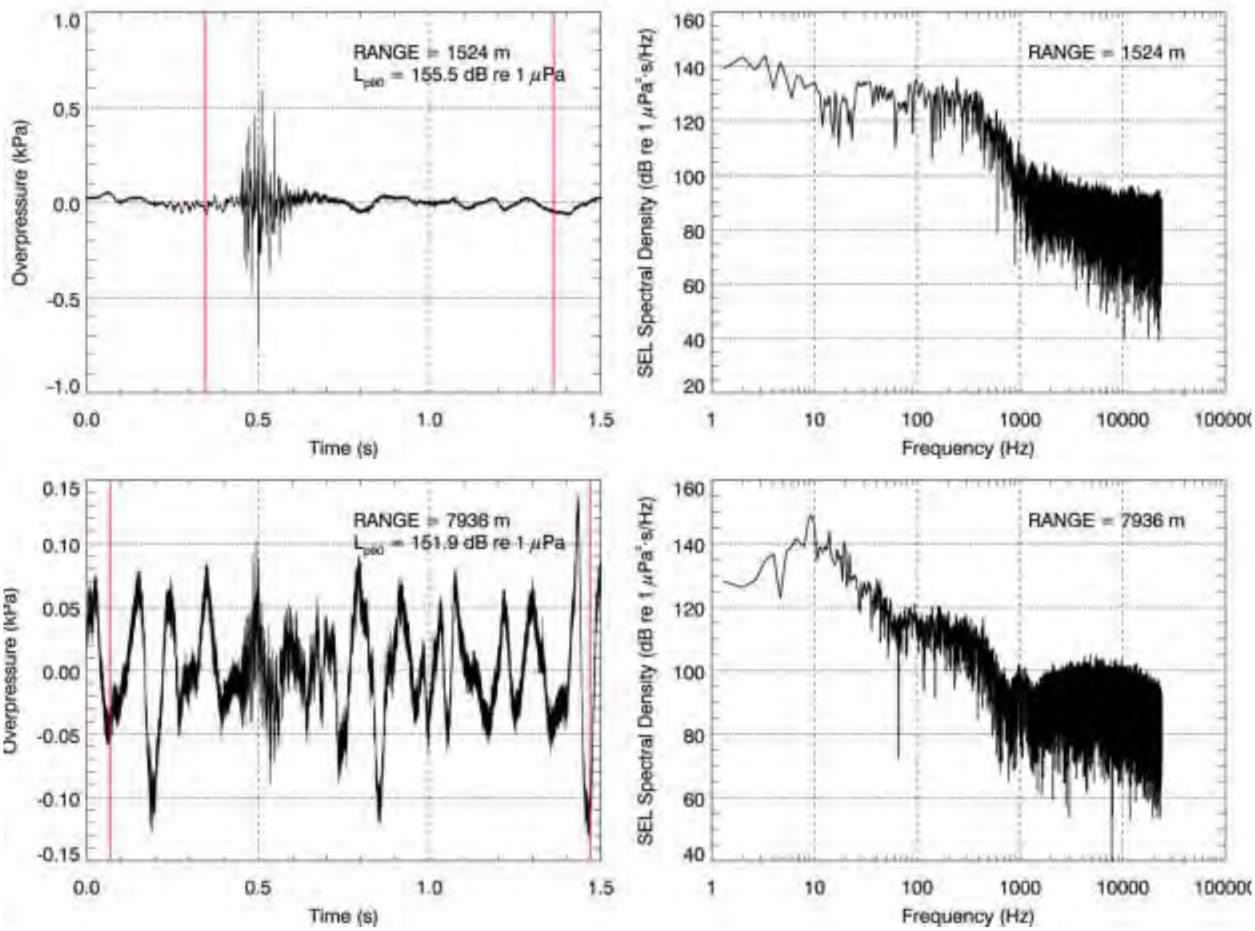


Figure 23. Waveform (left) and corresponding SEL spectral density (right) plots of 440 in³ airgun array pulses at various distances in the broadside direction at the nearshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.

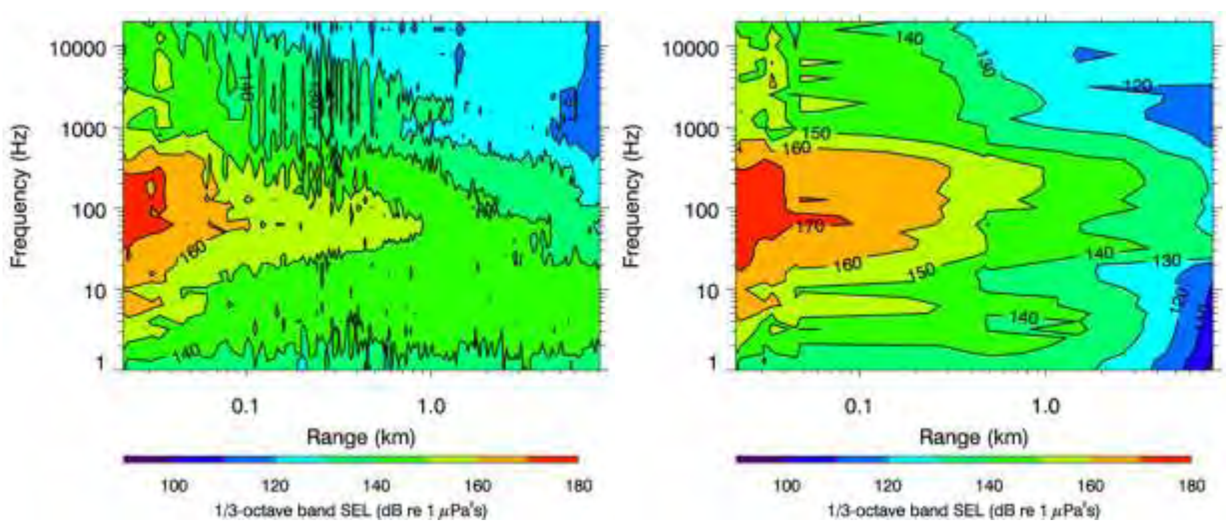


Figure 24. 1/3 octave band SEL levels as a function of range and frequency for the 440 in³ airgun array in the endfire (left) and broadside (right) directions at the nearshore site.

4.2.2. Track 2

Peak SPL, 90% rms SPL and SEL for each shot along the offshore line (Track 2) were computed from acoustic data recorded on OBHs E-H. Figure 25 shows sound levels from the 440 in³ airgun array versus slant range measured in the endfire and broadside directions. 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. Table 7 lists ranges to several rms SPL thresholds for each of the fits in Figure 25. Figures Figure 26 and Figure 27 illustrate how rms pulse duration varied with range in the endfire and broadside directions, with the rms SPL for comparison. Figure 28 presents spectrograms of 440 in³ airgun array pulses in the endfire direction at 546 m, 1583 m, 5477 m, and 8459 m. Pulses in the broadside direction near CPA at 80 m, 546 m, 1552 m, and 5505 m are shown in Figure 29. Figures Figure 30 and Figure 31 show waveforms and SEL spectral density plots of these same endfire and broadside pulses, respectively. Contour plots of 1/3-octave band levels versus range and frequency are shown in Figure 32. Sound levels near the source were highest between 30 and 200 Hz in the endfire direction and between 20 and 300 Hz in the broadside direction.

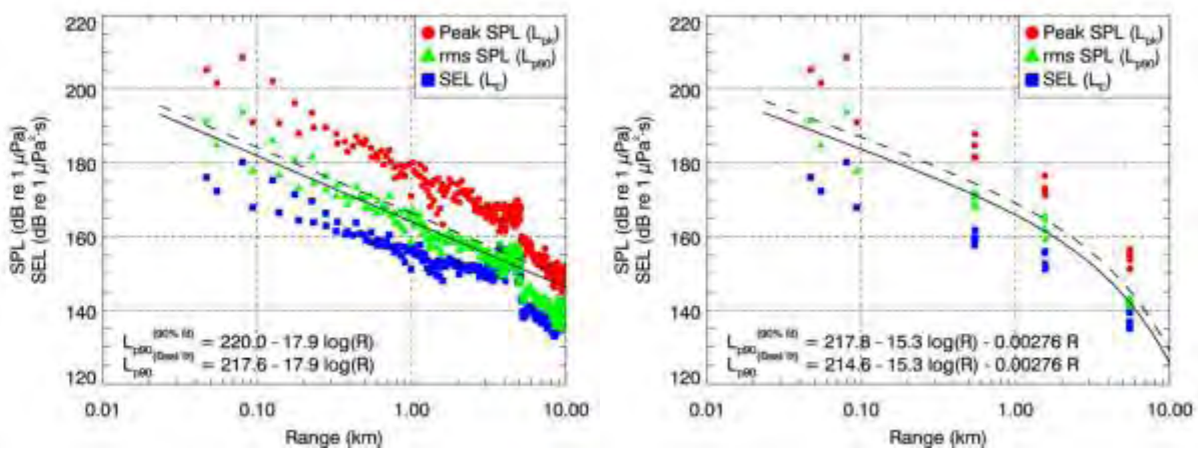


Figure 25: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 440 in³ airgun array pulses in the endfire (left) and broadside (right) directions measured at the offshore line (Track 2). Solid line is best fit of the empirical function to SPL_{rms90} values. Dashed line is the 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 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 25.

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

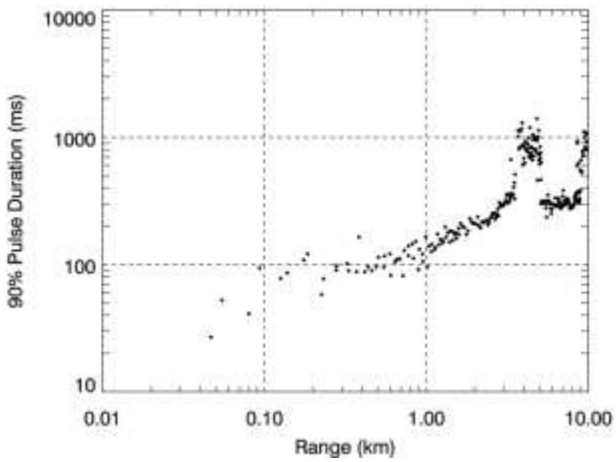


Figure 26. 440 in³ airgun array 90% pulse duration (left) and rms SPL (right) in the endfire direction as a function of range at the offshore site.

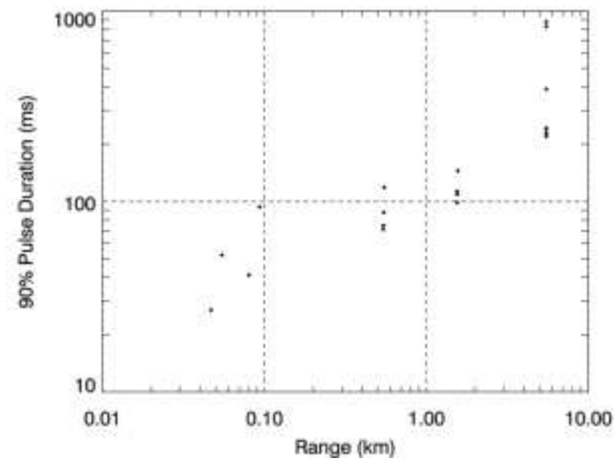


Figure 27. 440 in³ airgun array 90% pulse duration (left) and rms SPL (right) in the broadside direction as a function of range at the offshore site.

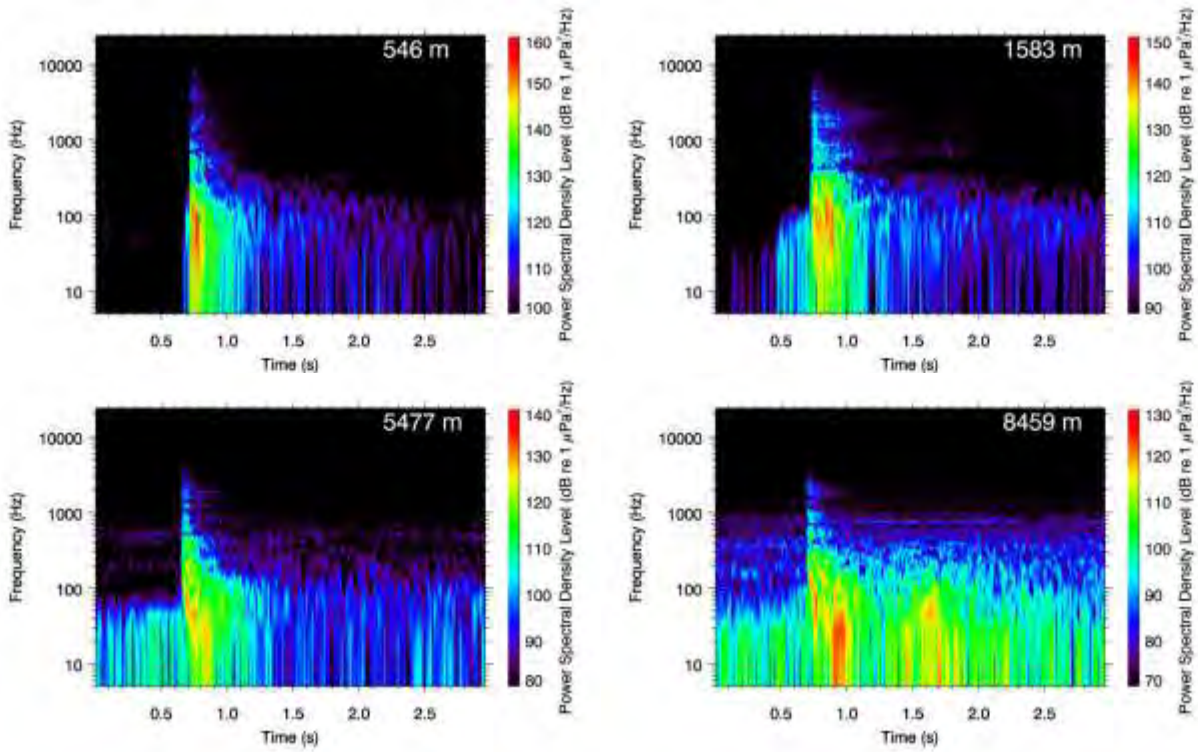


Figure 28. Spectrograms of airgun pulses from the 440 in³ airgun array at various distances in the endfire direction at the offshore site. 4096-pt FFT, 96 kHz sample rate, Hanning window.

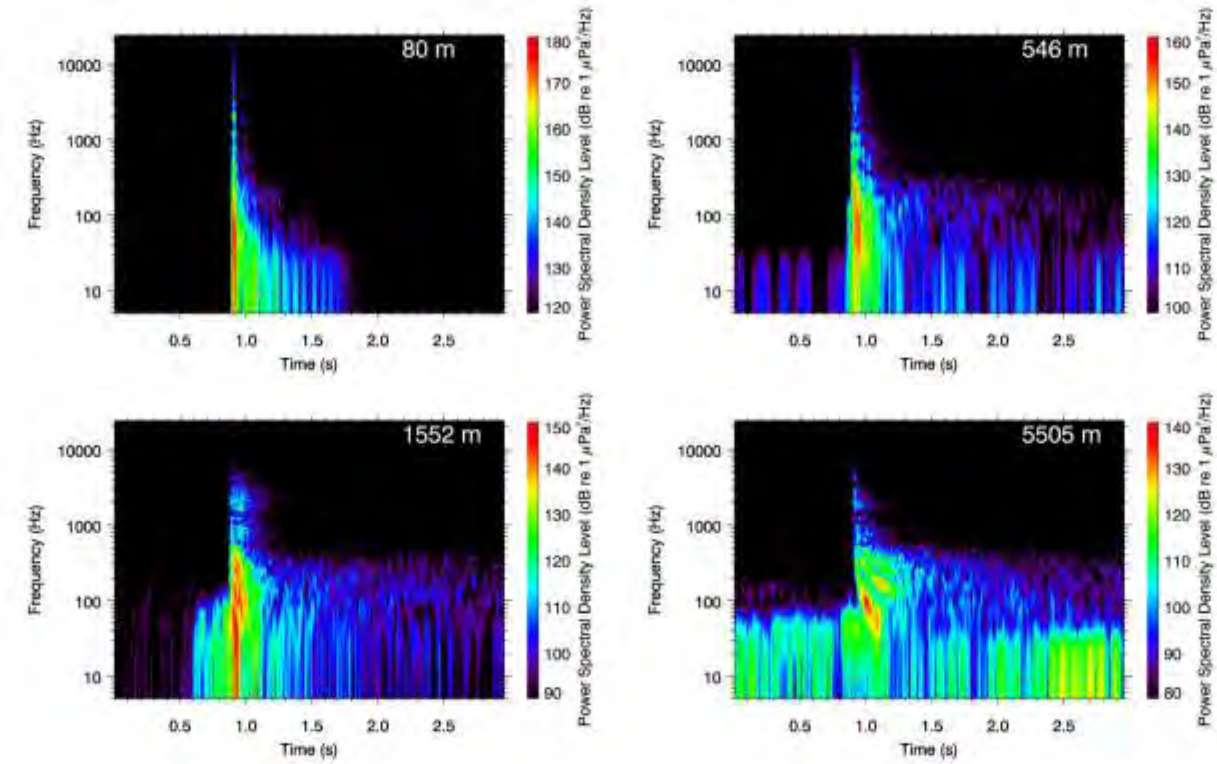
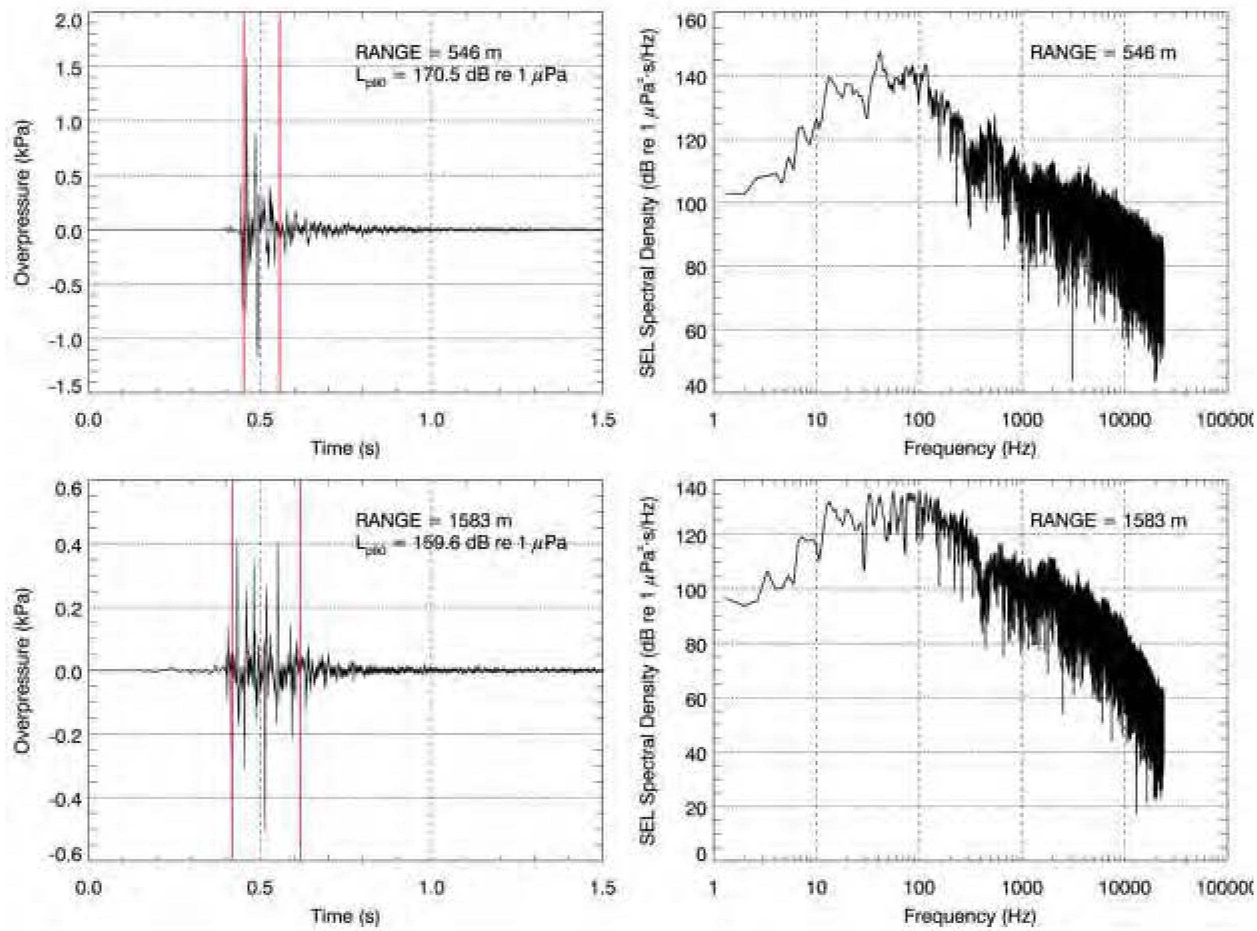


Figure 29. Spectrograms of airgun pulses from the 440 in³ airgun array at various distances in the broadside direction at the offshore site. 4096-pt FFT, 96 kHz sample rate, Hanning window (5505 m spectrogram is 2048-pt FFT, 48 kHz sample rate).


RANGE = 546 m
Lpk0 = 170.5 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 546 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)
RANGE = 1583 m
Lpk0 = 159.6 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 1583 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)

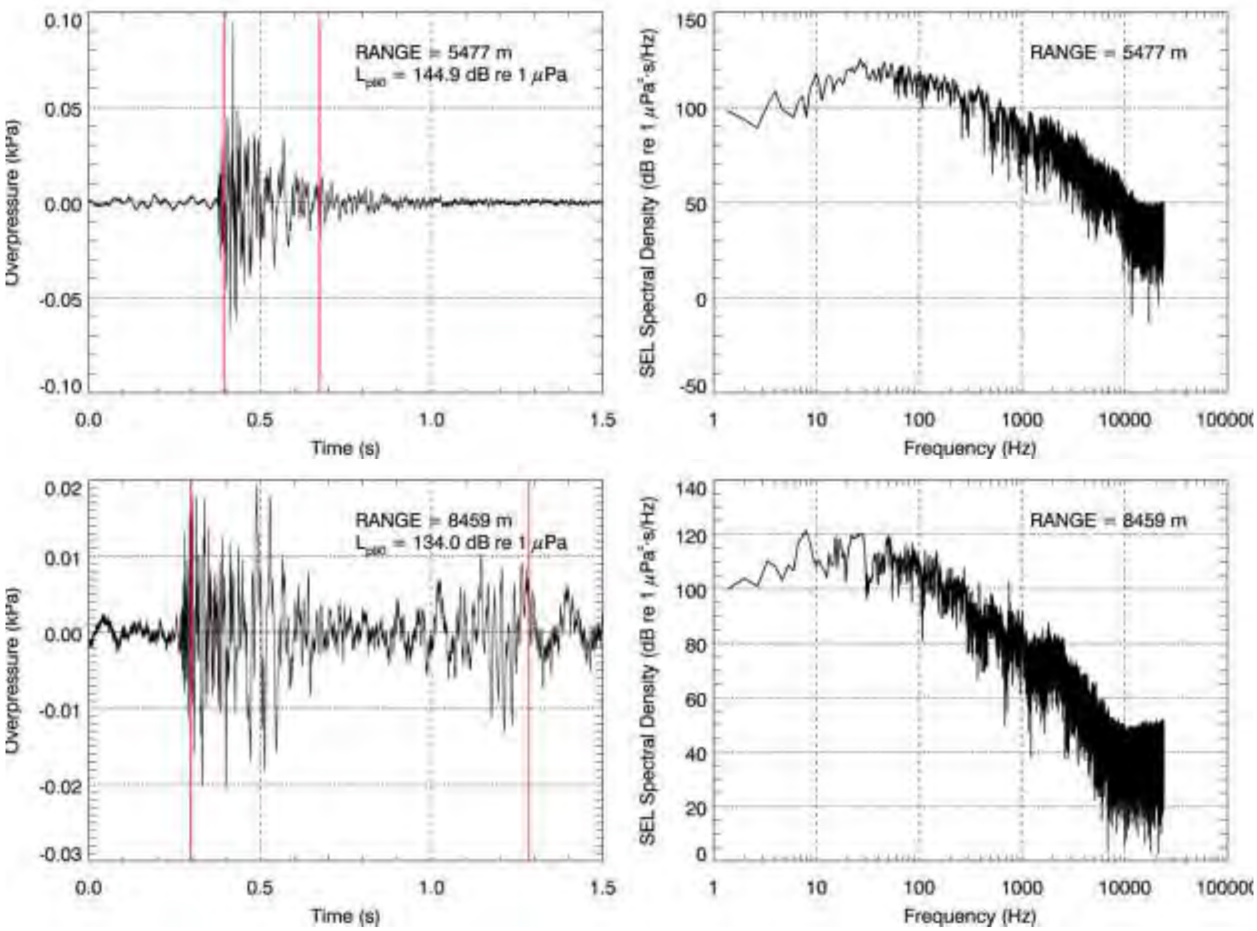
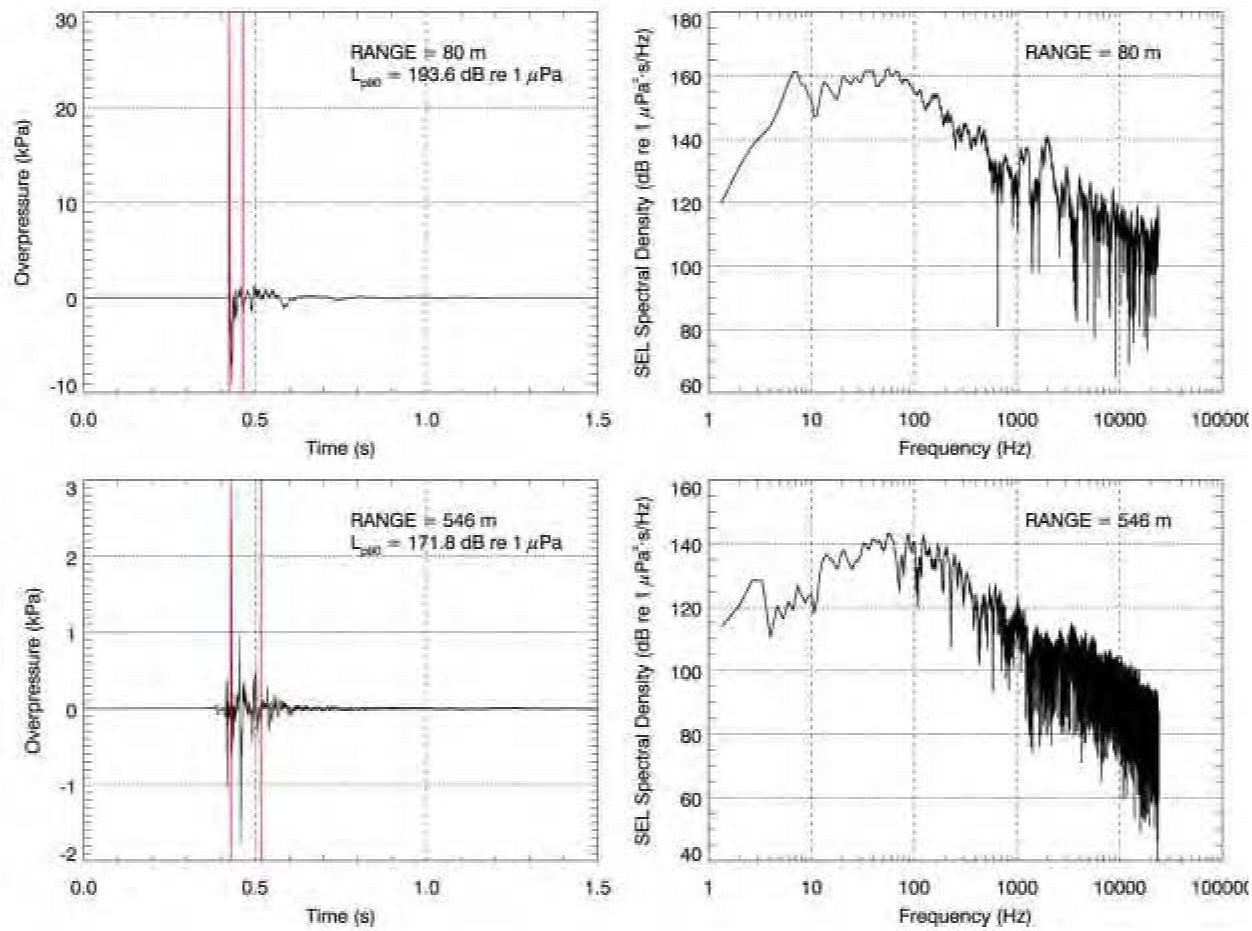


Figure 30. Waveform (left) and corresponding SEL spectral density (right) plots of 440 in³ airgun array pulses at various distances in the endfire direction at the offshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.


RANGE = 80 m
Lpeak = 193.6 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 80 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)
RANGE = 546 m
Lpeak = 171.8 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 546 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)

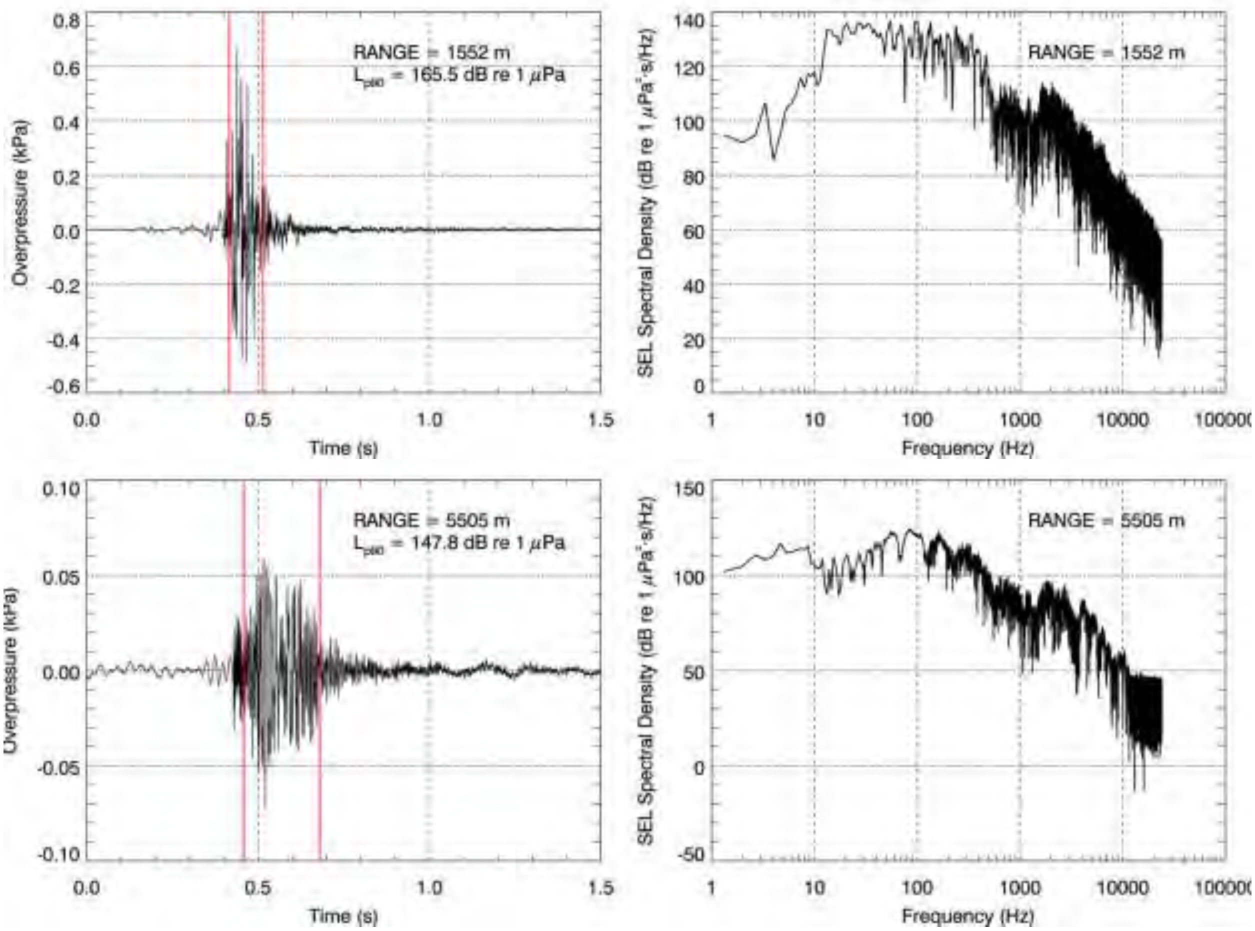


Figure 31. Waveform (left) and corresponding SEL spectral density (right) plots of 440 in³ airgun array pulses at various distances in the broadside direction at the offshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.

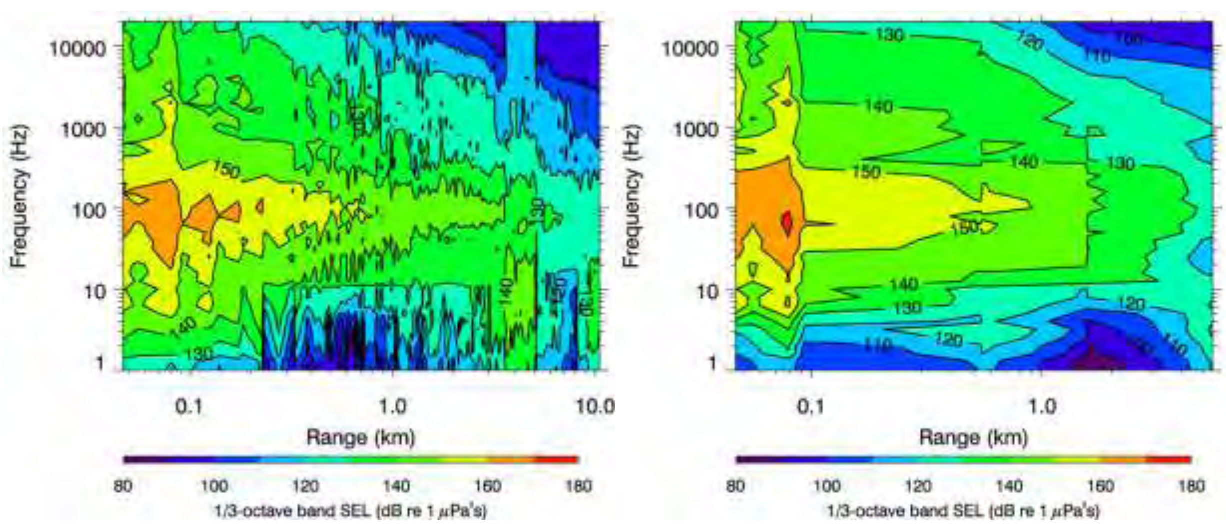


Figure 32. 1/3 octave band SEL levels as a function of range and frequency for the 440 in³ airgun array in the endfire (left) and broadside (right) directions at the offshore site.

4.3. 1200 in^3 Airgun Array

4.3.1. Track 1

Peak SPL, 90% rms SPL and SEL for each shot on the nearshore line (Track 1) were computed from acoustic data recorded on OBHs A-D. Figure 33 shows sound levels from the 1200 in³ airgun array versus slant range measured in the endfire and broadside directions. 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. Table 8 lists ranges to several rms SPL thresholds for each of the fits in Figure 33. Figures Figure 34 and Figure 35 illustrate how rms pulse duration varied with range in the endfire and broadside directions, with the rms SPL for comparison. Figure 36 presents spectrograms of 1200 in³ airgun array pulses in the endfire direction at 393 m, 1416 m, and 6271 m. Pulses in the broadside direction near CPA at 107 m, 380 m, 1429 m, and 7840 m are shown in Figure 37. Figures Figure 38 and Figure 39 show waveforms and SEL spectral density plots of these same endfire and broadside pulses, respectively. Contour plots of 1/3-octave band levels versus range and frequency are shown in Figure 40. Sound levels near the source were highest between 80 and 300 Hz in both the endfire and broadside directions.

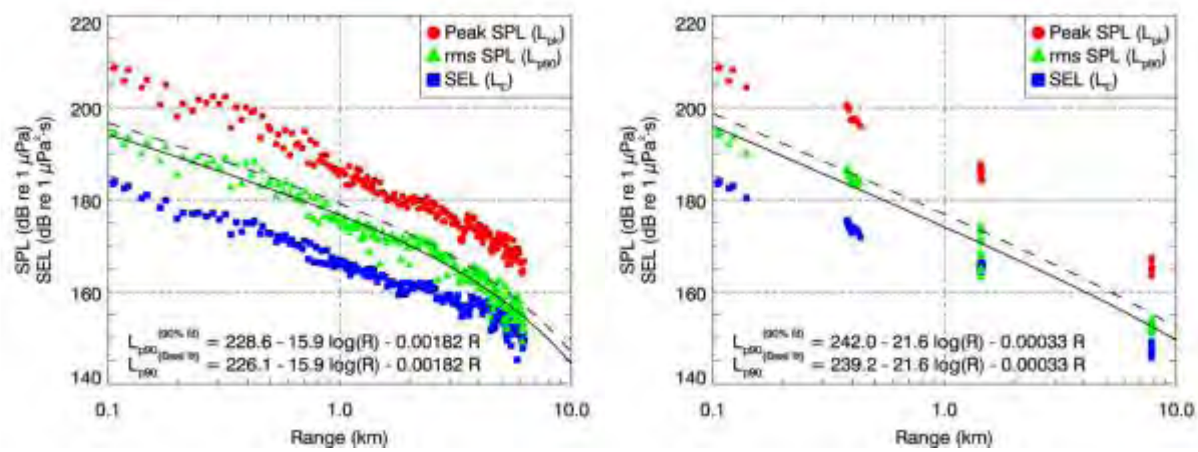


Figure 33: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 1200 in^3 airgun array pulses in the endfire (left) and broadside (right) directions measured at the nearshore site (Track 1). Solid line is best fit of the empirical function to SPL_{rms90} values. Dashed line is the best-fit adjusted to exceed 90% of the SPL_{rms90} values.

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 33.

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

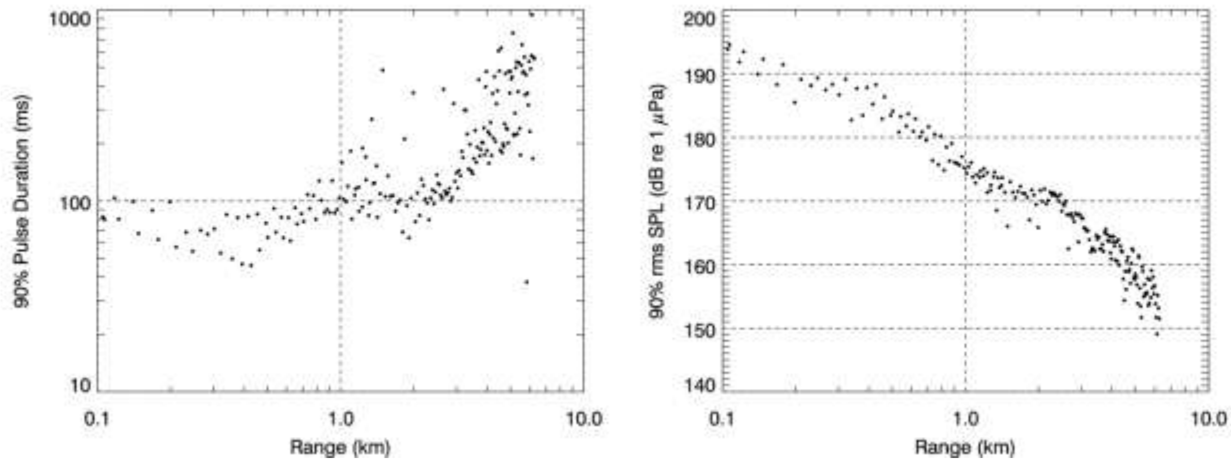


Figure 34. 1200 in³ airgun array 90% pulse duration (left) and rms SPL (right) in the endfire direction as a function of range at the nearshore site.

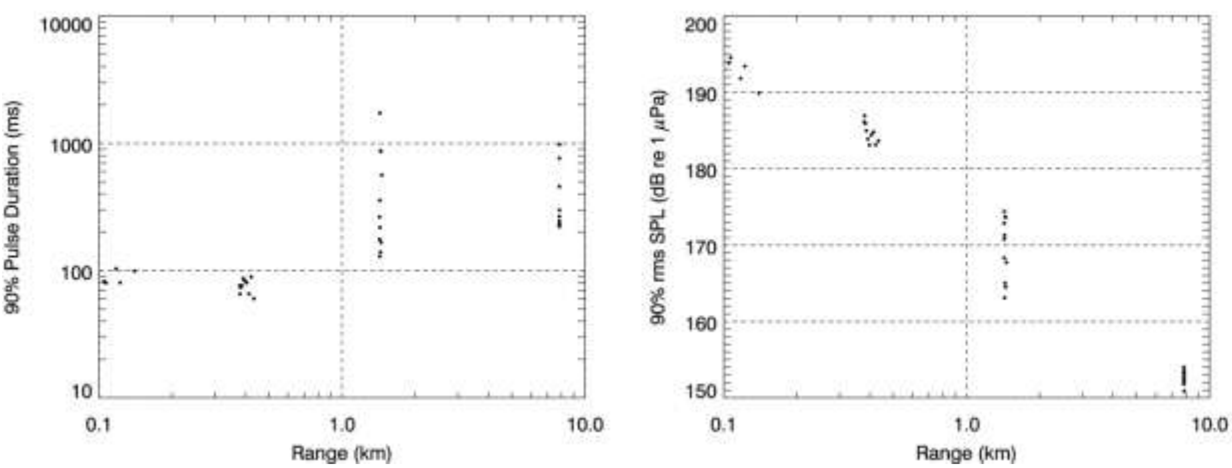


Figure 35. 1200 in³ airgun array 90% pulse duration (left) and rms SPL (right) in the broadside direction as a function of range at the nearshore site.

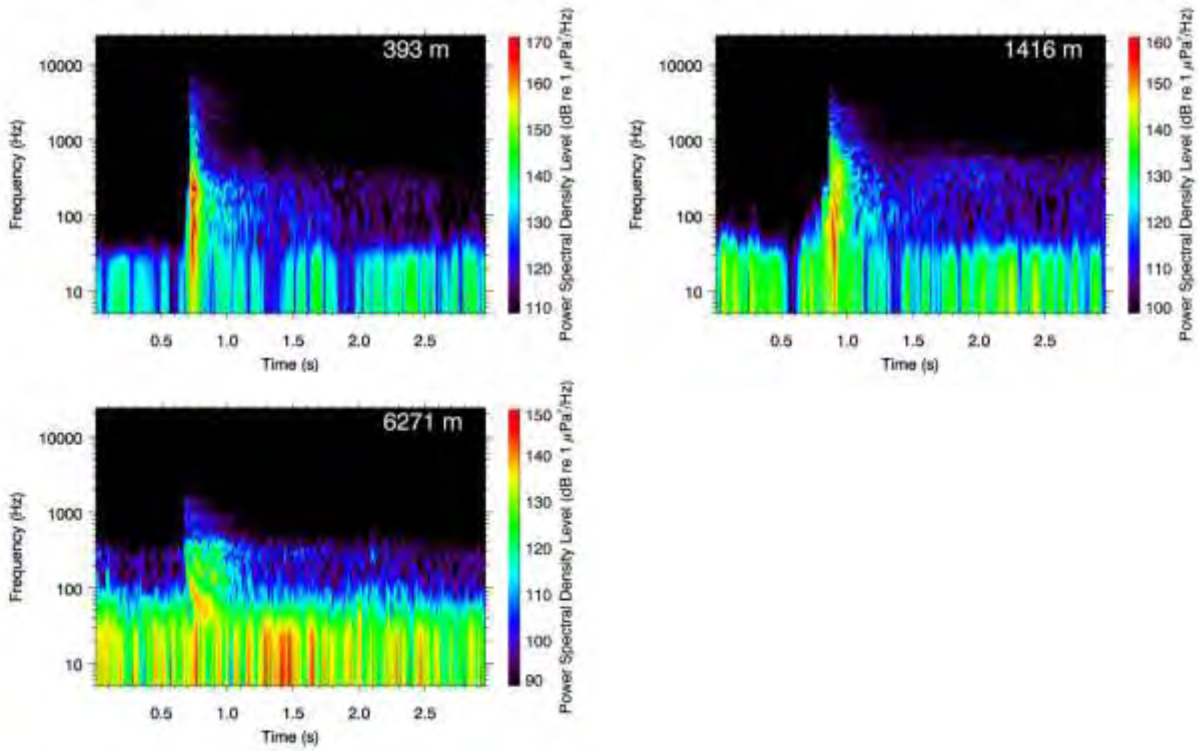


Figure 36. Spectrograms of airgun pulses from the 1200 in³ airgun array at various distances in the endfire direction at the nearshore site. 2048-pt FFT, 48 kHz sample rate, Hanning window.

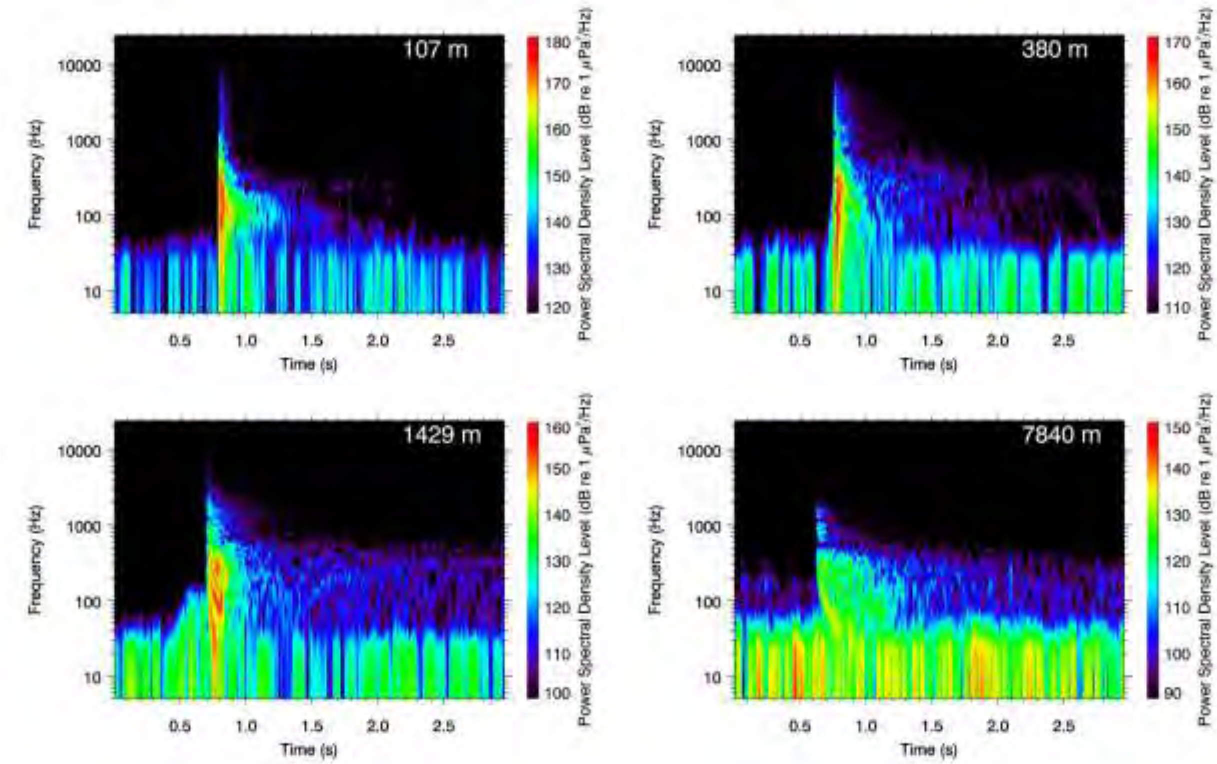


Figure 37. Spectrograms of airgun pulses from the 1200 in³ airgun array at various distances in the broadside direction at the nearshore site. 2048-pt FFT, 48 kHz sample rate, Hanning window.

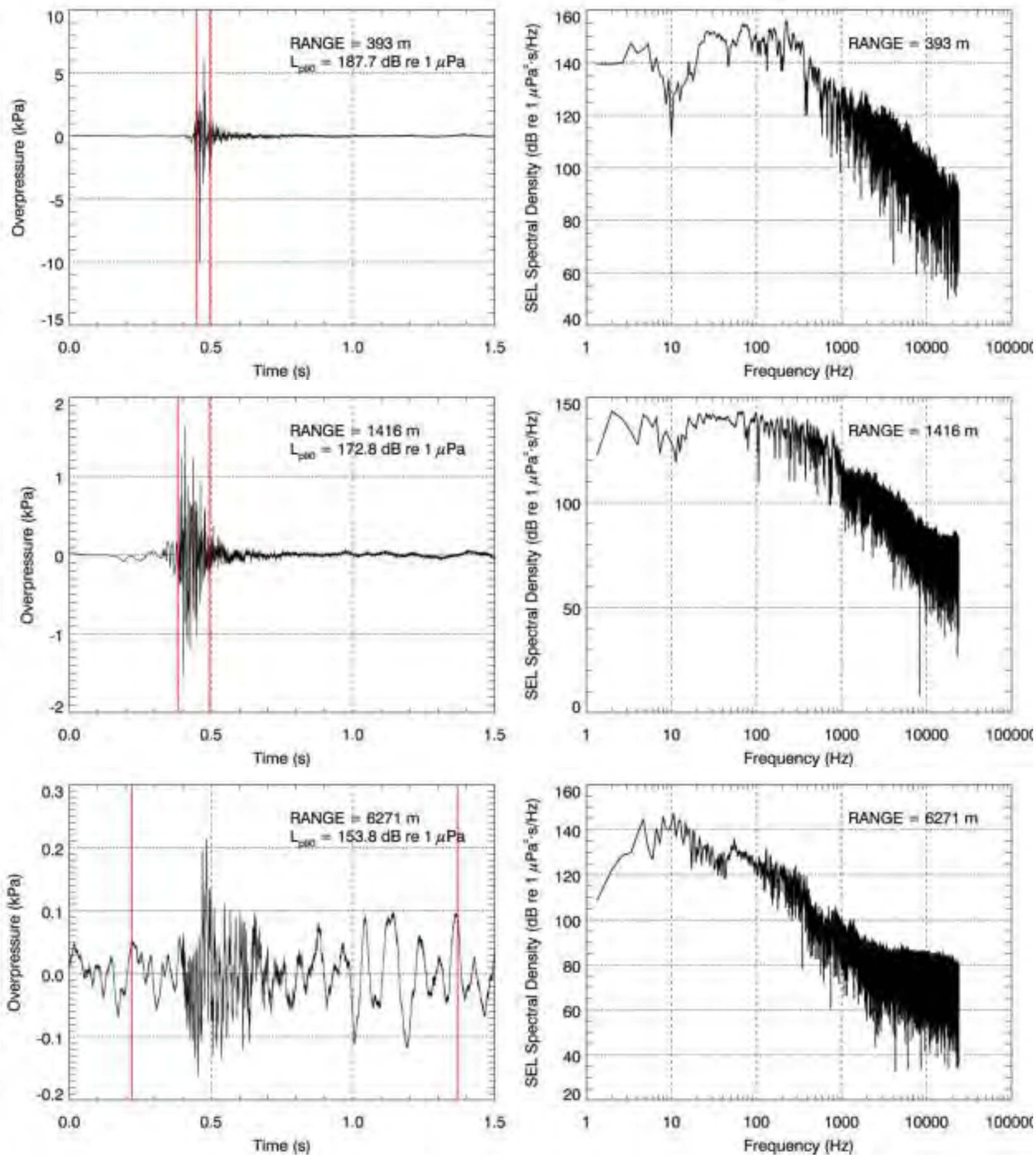
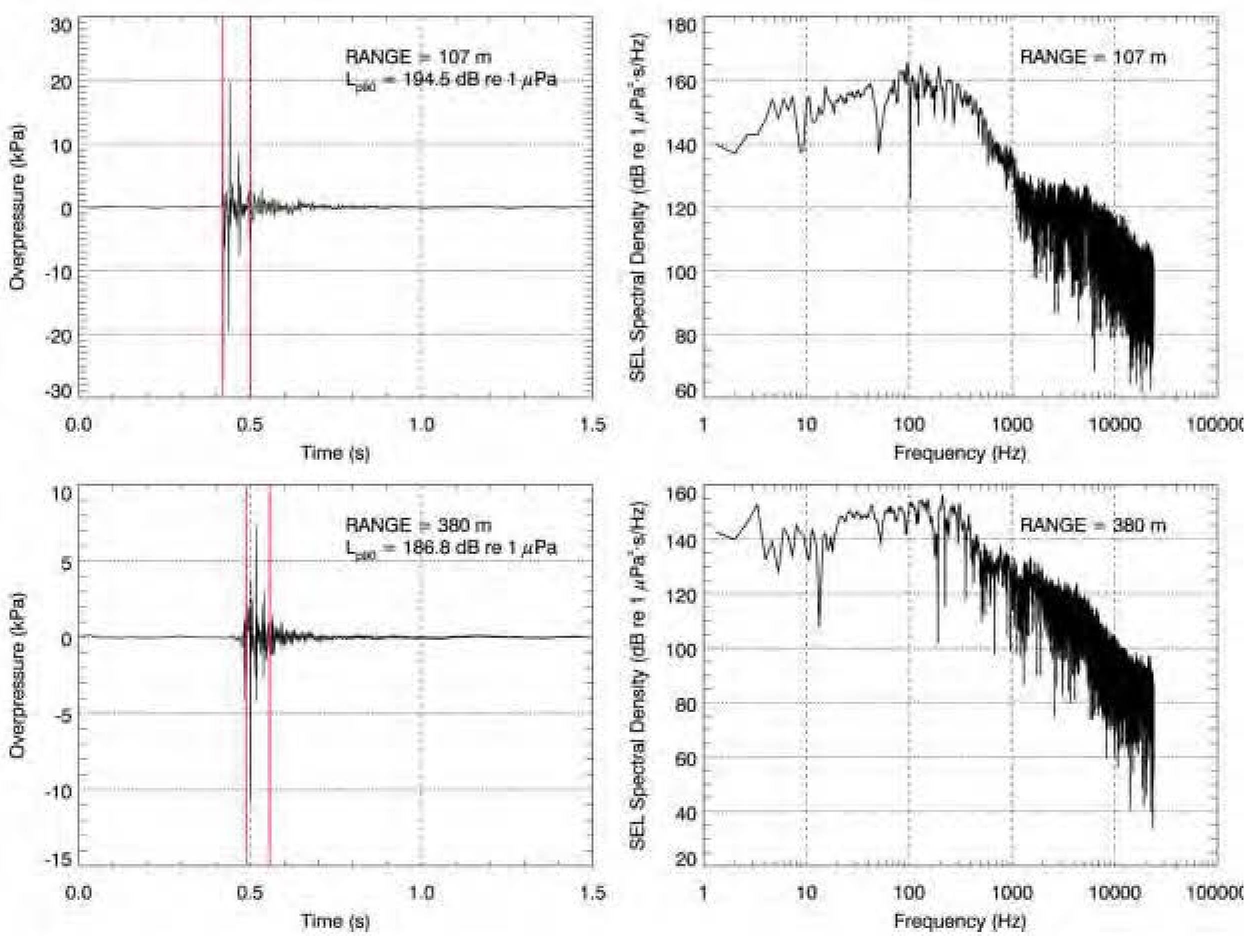


Figure 38. Waveform (left) and corresponding SEL spectral density (right) plots of 1200 in³ airgun array pulses at various distances in the endfire direction at the nearshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.


RANGE = 107 m
L_{pk0} = 194.5 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 107 m
SEL Spectral Density (dB re 1 μPa^2·s/Hz)
Frequency (Hz)
RANGE = 380 m
L_{pk0} = 186.8 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 380 m
SEL Spectral Density (dB re 1 μPa^2·s/Hz)
Frequency (Hz)

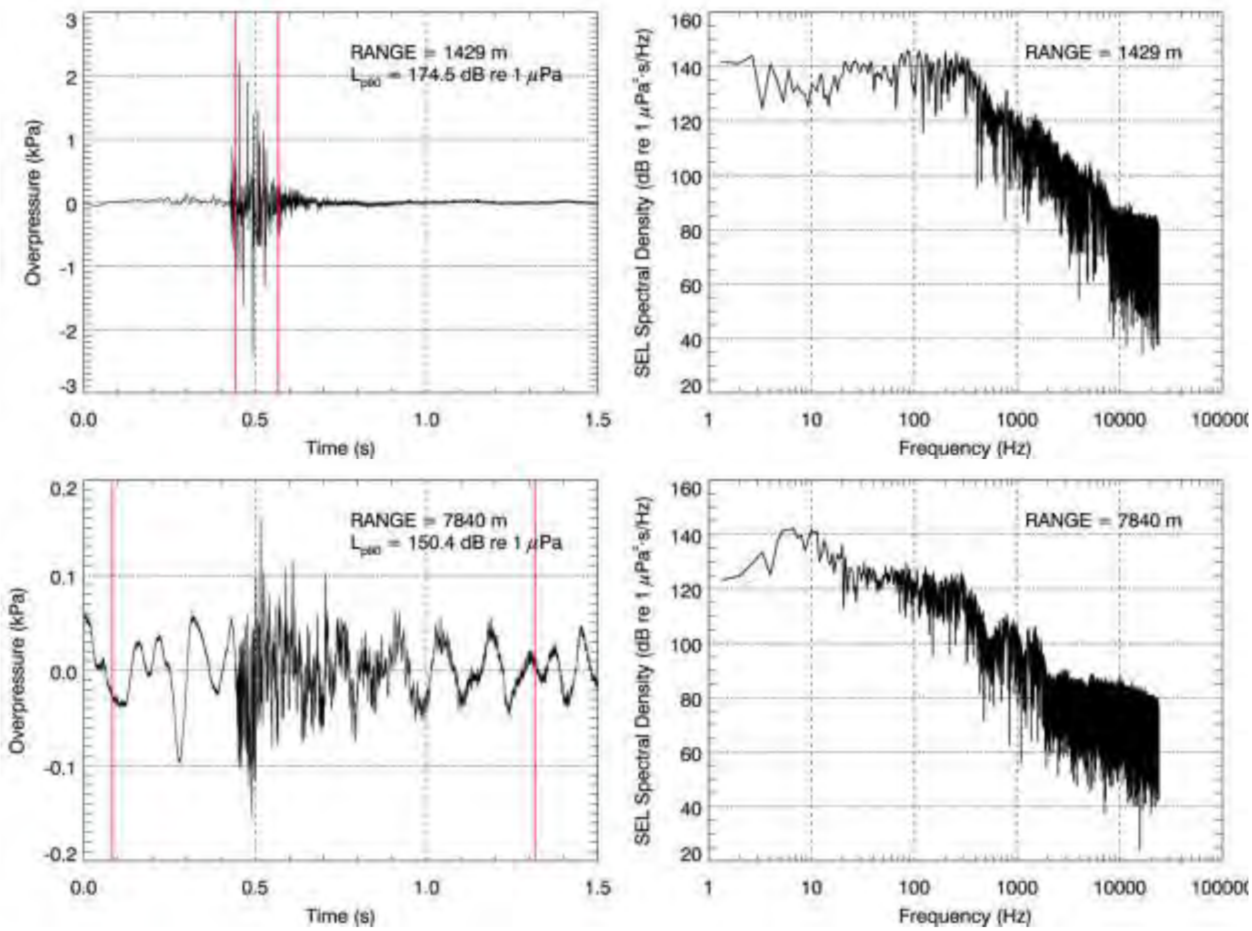


Figure 39. Waveform (left) and corresponding SEL spectral density (right) plots of 1200 in³ airgun array pulses at various distances in the broadside direction at the nearshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.

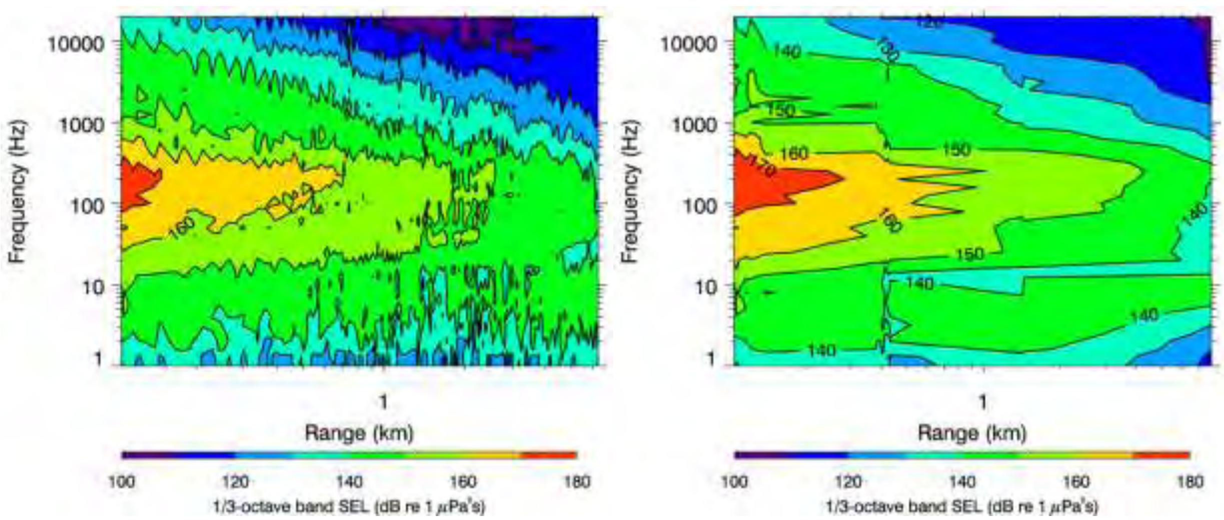


Figure 40. 1/3 octave band SEL levels as a function of range and frequency for the 1200 in³ airgun array in the endfire (left) and broadside (right) directions at the nearshore site.

4.3.2. Track 2

Peak SPL, 90% rms SPL and SEL for each shot on the offshore line were computed from acoustic data recorded on OBHs E-H. Figure 41 shows sound levels from the 1200 in³ airgun array versus slant range measured in the endfire and broadside directions. 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. Table 9 lists ranges to several rms SPL thresholds for each of the fits in Figure 41. 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. Figures Figure 42 and Figure 43 illustrate how rms pulse duration varied with range in the endfire and broadside directions, with the rms SPL for comparison. Figure 44 presents spectrograms of 1200 in³ airgun array pulses in the endfire direction at 574 m, 1553 m, 5480 m, and 6418 m. Pulses in the broadside direction near CPA at 75 m, 570 m, 1558 m, and 5509 m are shown in Figure 45. Figures Figure 46 and Figure 47 show waveforms and SEL spectral density plots of these same endfire and broadside pulses, respectively. Contour plots of 1/3-octave band levels versus range and frequency are shown in Figure 48. Sound levels near the source were highest between 30 and 200 Hz in the endfire direction and between 20 and 200 Hz in the broadside direction.

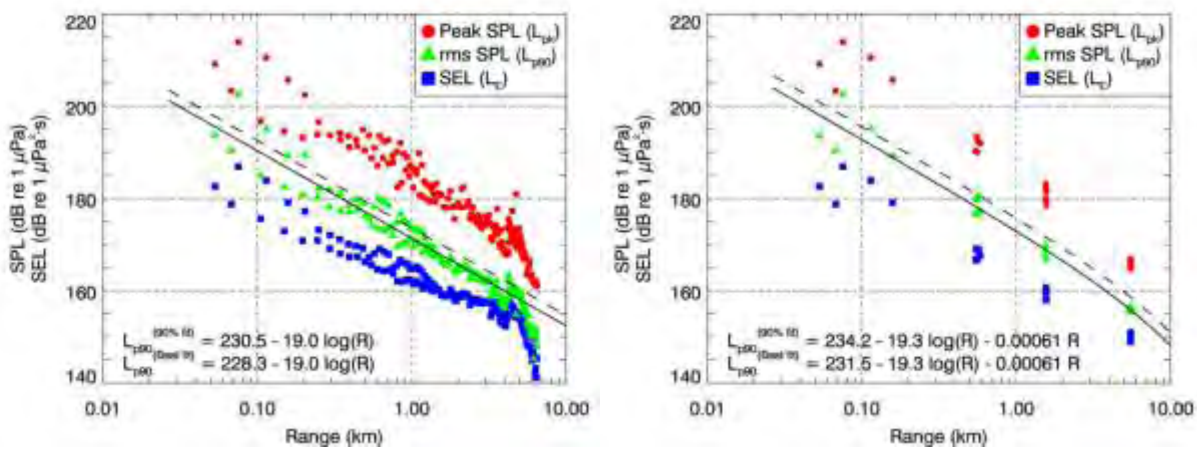


Figure 41: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 1200 in^3 airgun array pulses in the endfire (left) and broadside (right) directions measured at the offshore sites (Track 2). Solid line is best fit of the empirical function to SPL$_{rms90}$ values. Dashed line 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 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 41.

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

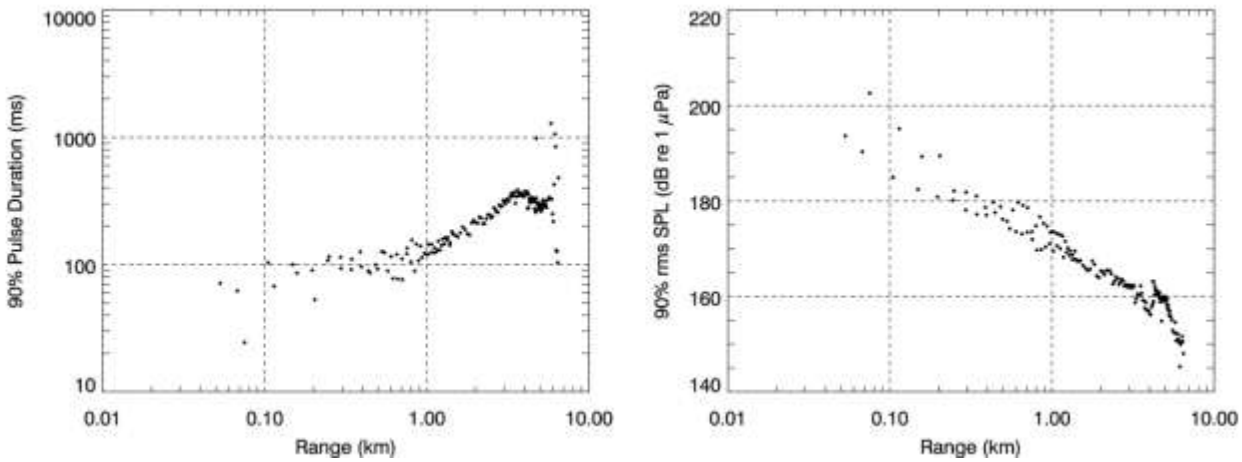


Figure 42. 1200 in³ airgun array 90% pulse duration (left) and rms SPL (right) in the endfire direction as a function of range at the offshore site.

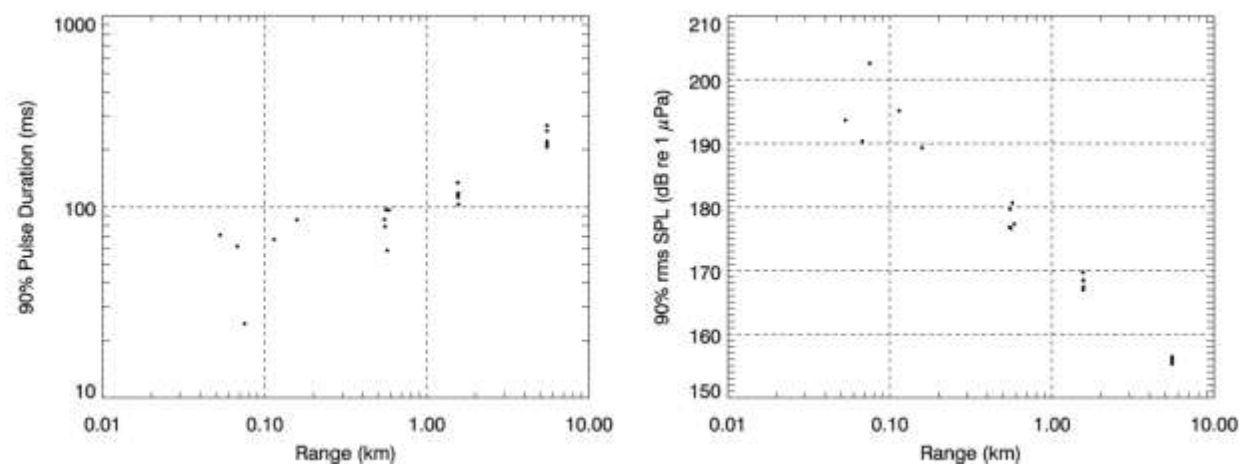


Figure 43. 1200 in³ airgun array 90% pulse duration (left) and rms SPL (right) in the broadside direction as a function of range at the offshore site.

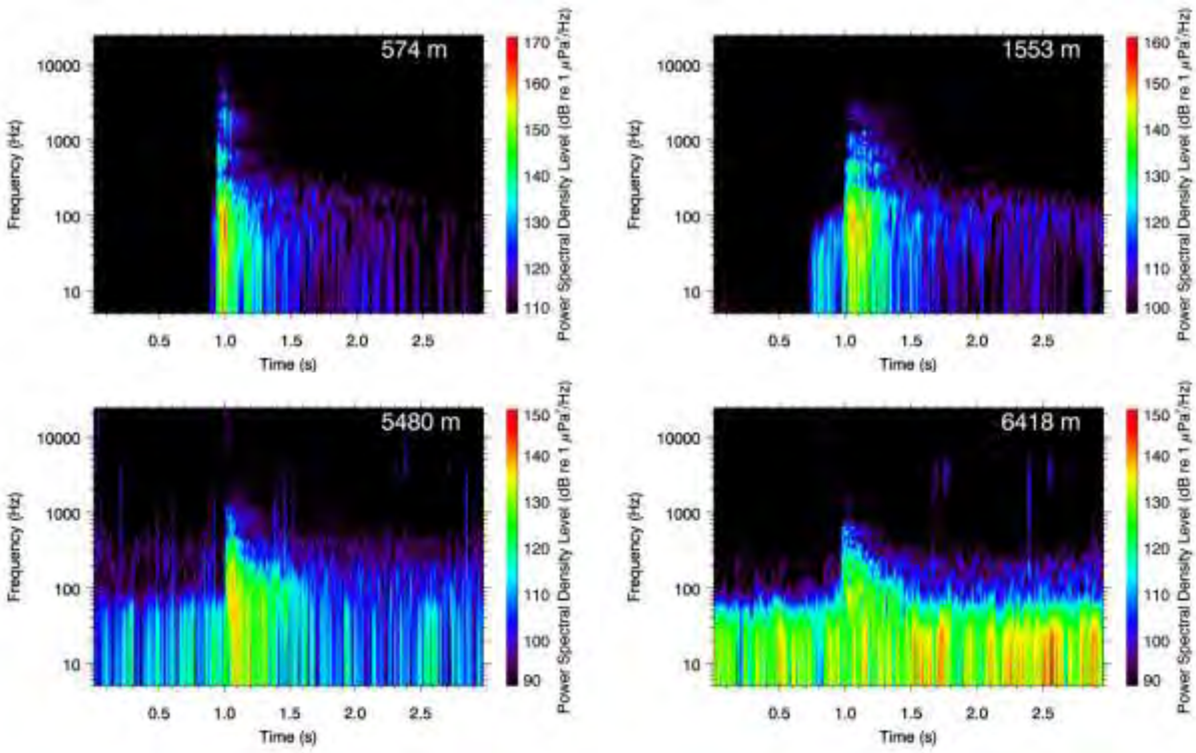


Figure 44. Spectrograms of airgun pulses from the 1200 in³ airgun array at various distances in the endfire direction at the offshore site. 4096-pt FFT, 96 kHz sample rate, Hanning window.

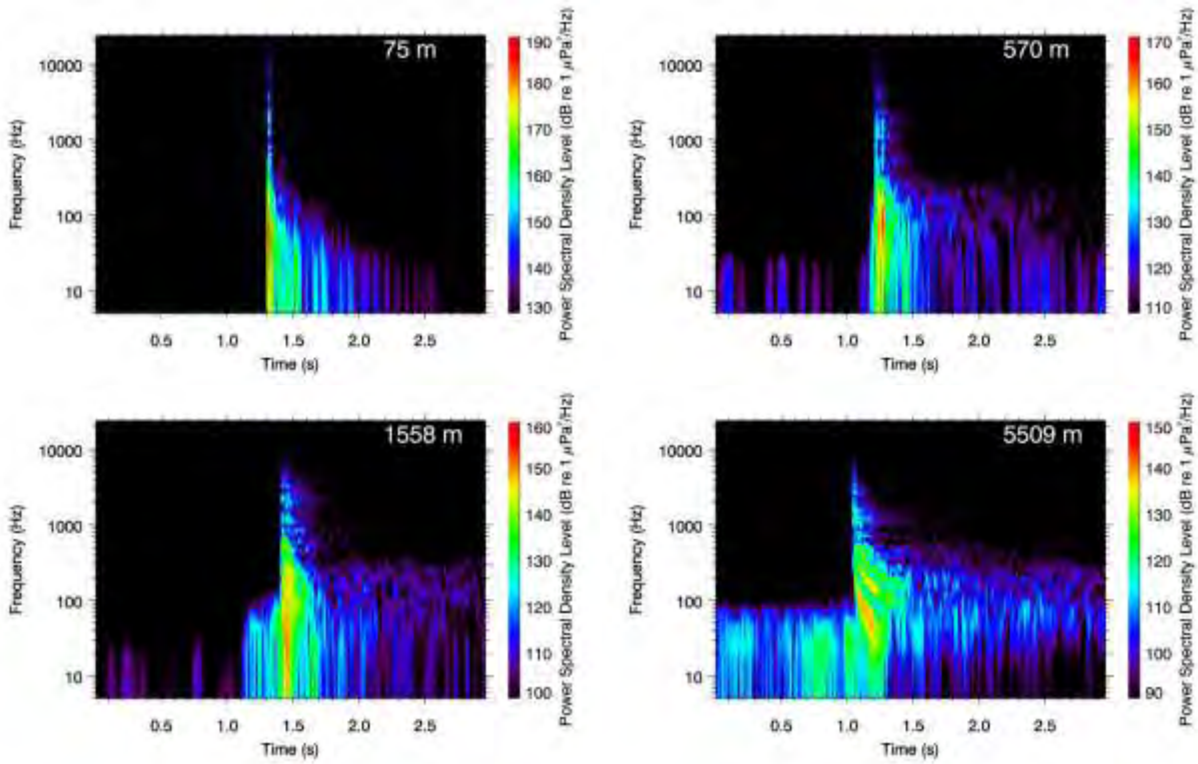
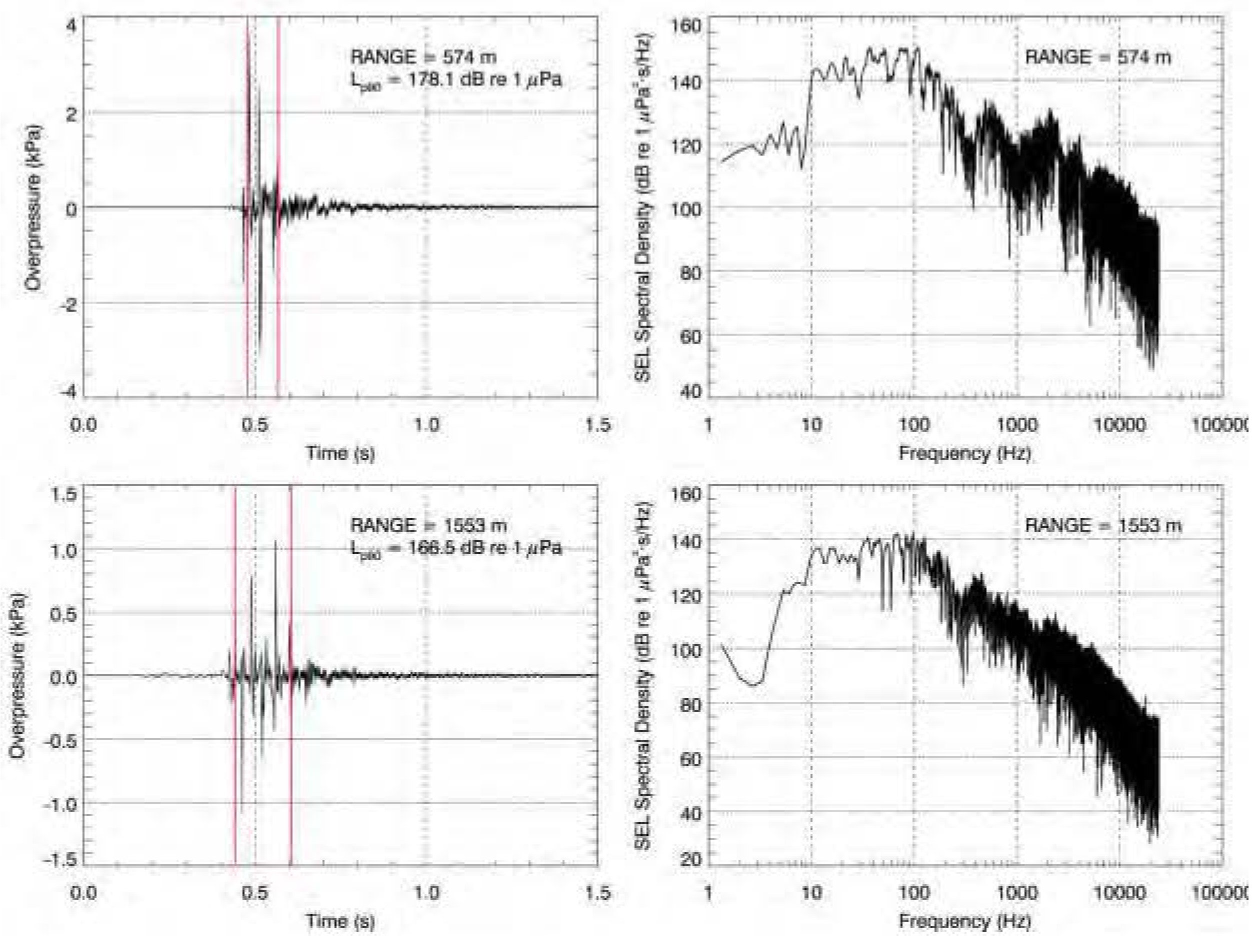


Figure 45. Spectrograms of airgun pulses from the 1200 in³ airgun array at various distances in the broadside direction at the offshore site. 4096-pt FFT, 96 kHz sample rate, Hanning window (5509 m spectrogram is 2048-pt FFT, 48 kHz sample rate).


RANGE = 574 m
L_{pk} = 178.1 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 574 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)
RANGE = 1553 m
L_{pk} = 166.5 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 1553 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)

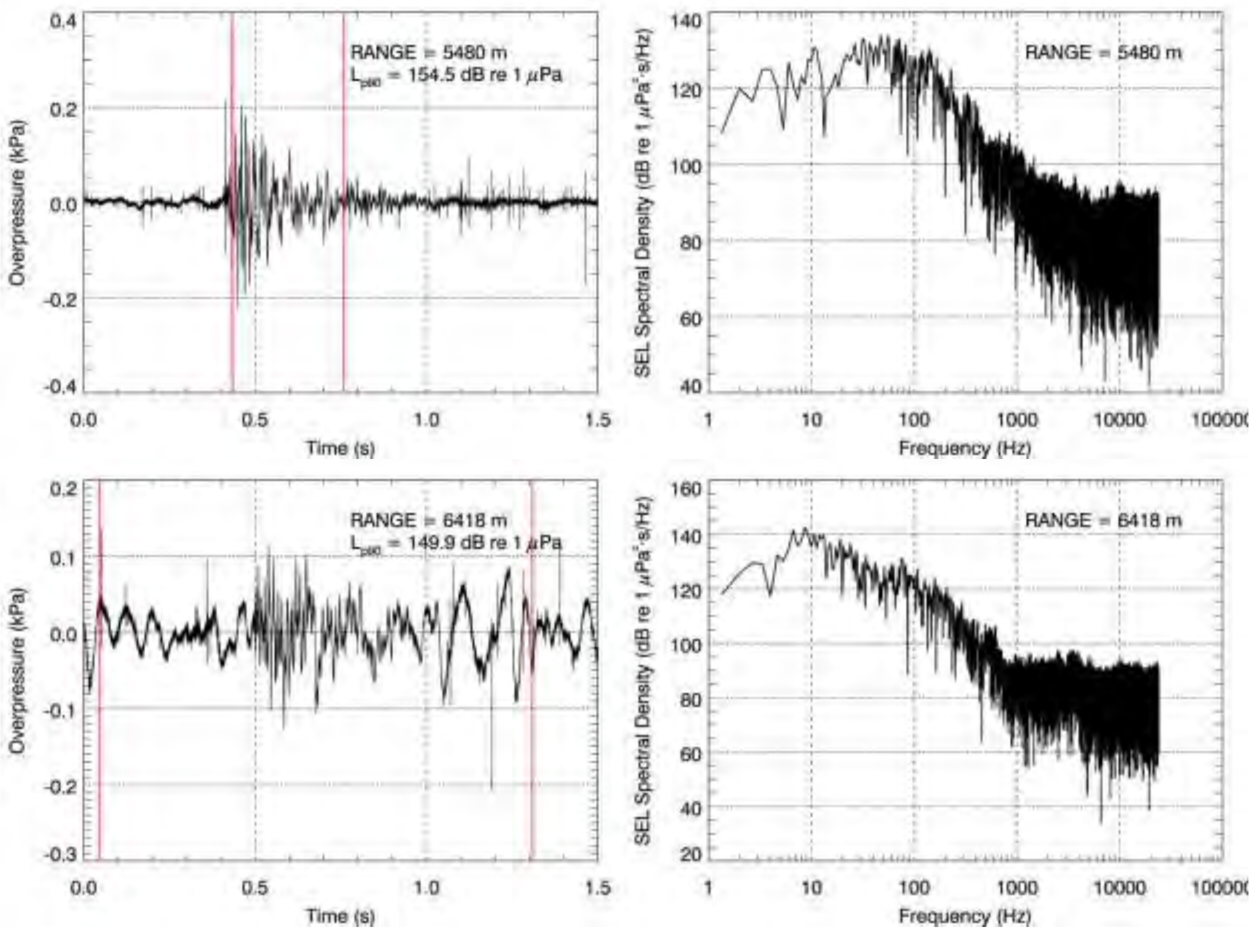
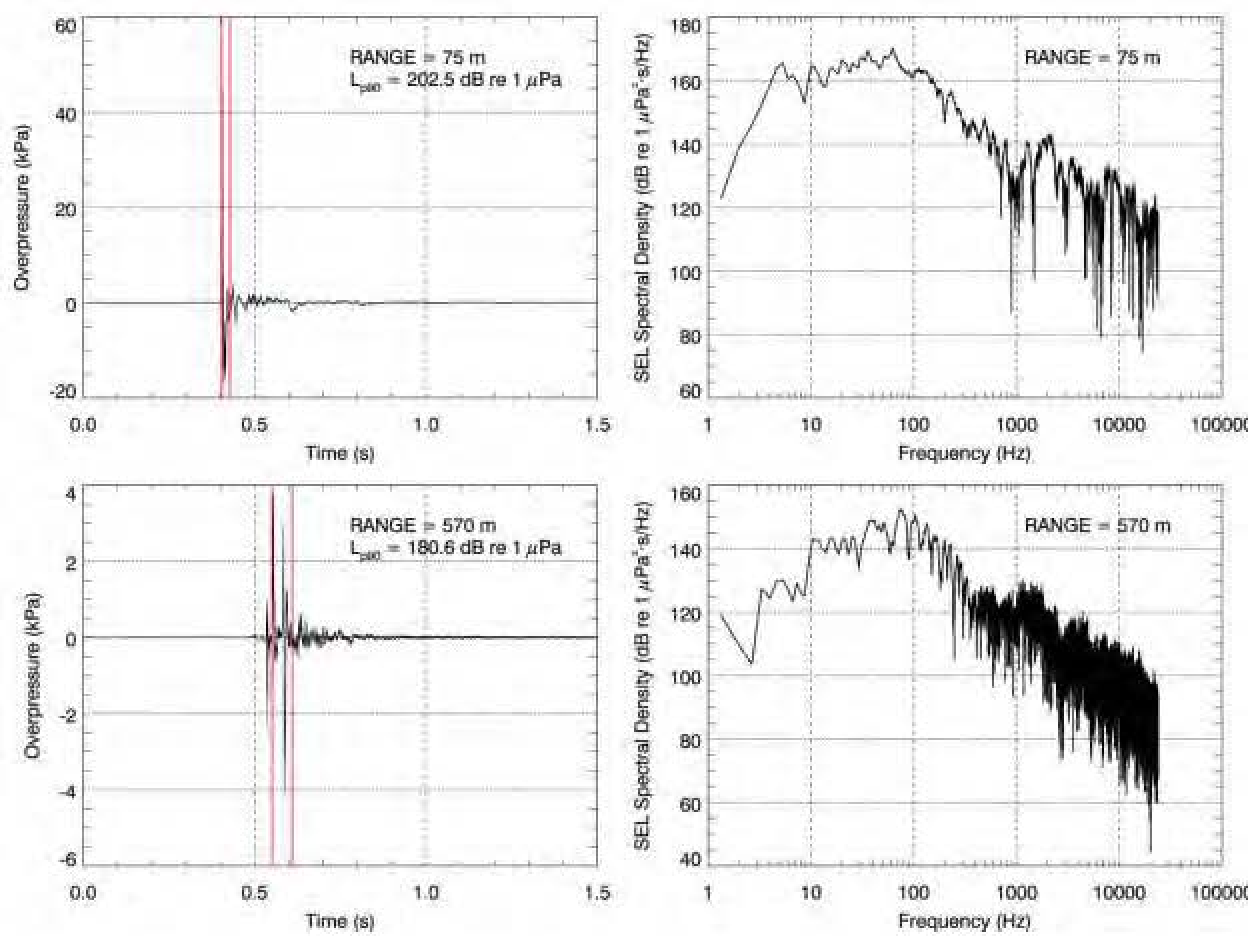


Figure 46. Waveform (left) and corresponding SEL spectral density (right) plots of 1200 in³ airgun array pulses at various distances in the endfire direction at the offshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.


RANGE = 75 m
L_{pk0} = 202.5 dB re 1 μPa
Overpressure (kPa)
Time (s)
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)
RANGE = 75 m
RANGE = 570 m
L_{pk0} = 180.6 dB re 1 μPa
Overpressure (kPa)
Time (s)
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)
RANGE = 570 m

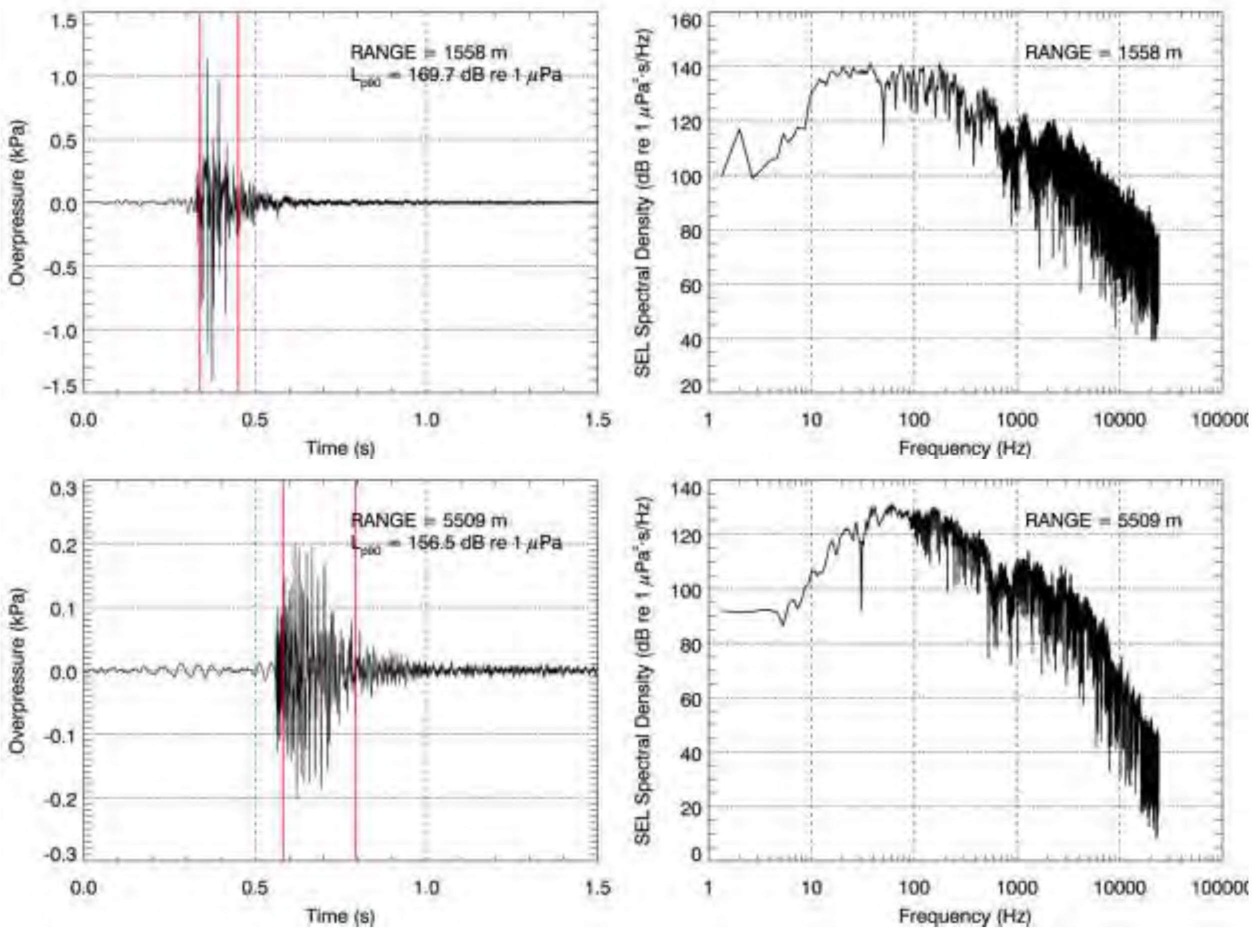


Figure 47. Waveform (left) and corresponding SEL spectral density (right) plots of 1200 in³ airgun array pulses at various distances in the broadside direction at the offshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.

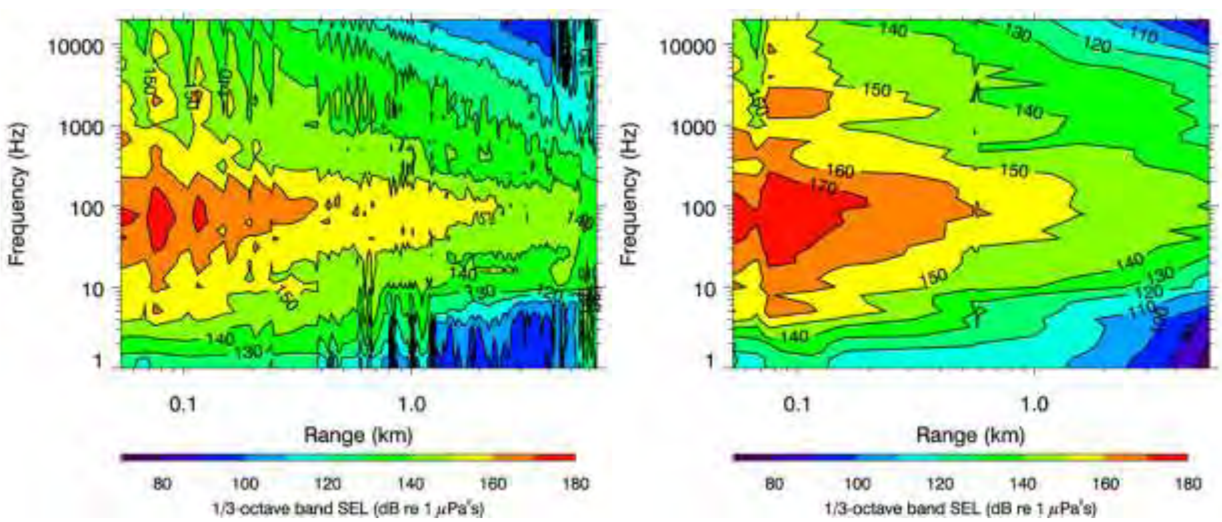


Figure 48. 1/3 octave band SEL levels as a function of range and frequency for the 1200 in³ airgun array in the endfire (left) and broadside (right) directions at the offshore site.

4.4. 2400 in^3 Airgun Array

4.4.1. Track 1

Peak SPL, 90% rms SPL and SEL for each shot on the nearshore line were computed from acoustic data recorded on OBHs A-D. Figure 49 shows sound levels from the 2400 in^3 airgun array versus slant range measured in the endfire and broadside directions. 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. Table 10 lists ranges to several rms SPL thresholds for each of the fits in Figure 49. 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). Figures Figure 50 and Figure 51 illustrate how rms pulse duration varied with range in the endfire and broadside directions, with the rms SPL for comparison. Figure 52 presents spectrograms of 2400 in^3 airgun array pulses in the endfire direction at 484 m, 1510 m, 7922 m, and 8993 m. Pulses in the broadside direction near CPA at 42 m, 477 m, 1524 m, and 7949 m are shown in Figure 53. Figures Figure 54 and Figure 55 show waveforms and SEL spectral density plots of these same endfire and broadside pulses, respectively. Contour plots of 1/3-octave band levels versus range and frequency are shown in Figure 56. Sound levels near the source were highest between 30 and 150 Hz in the endfire direction and between 50 and 200 Hz in the broadside direction.

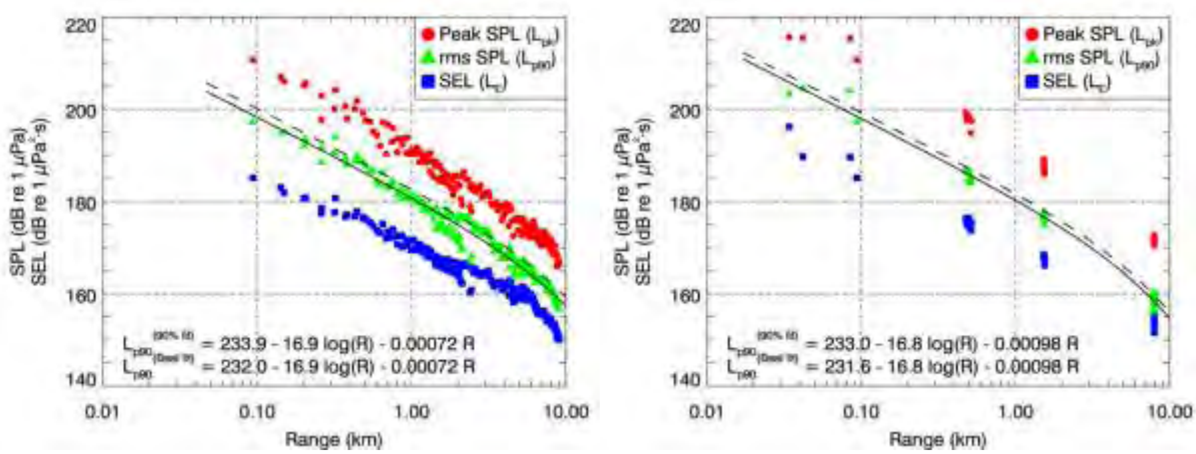


Figure 49: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 2400 in^3 airgun array pulses in the endfire (left) and broadside (right) directions measured at the nearshore sites (track 1). Solid line is best fit of the empirical function to SPL_{rms90} values. Dashed line is the best-fit adjusted to exceed 90% of the SPL_{rms90} values.

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 49.

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

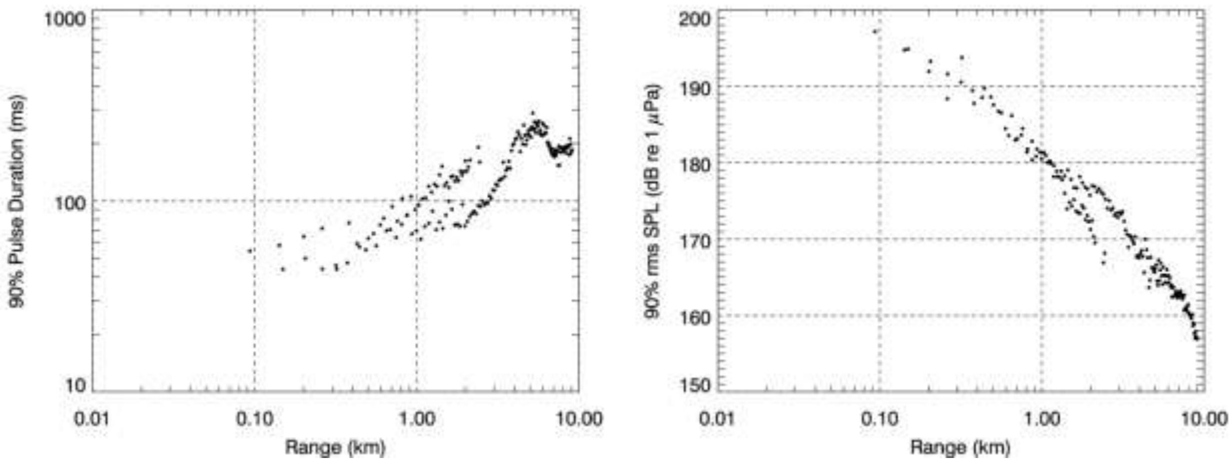


Figure 50. 2400 in³ airgun array 90% pulse duration (left) and rms SPL (right) in the endfire direction as a function of range at the nearshore site.

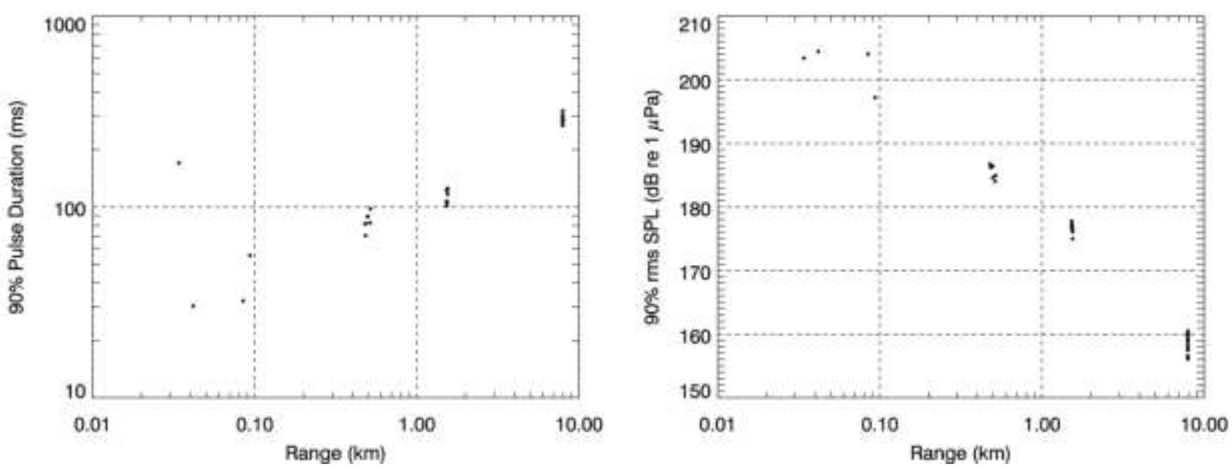


Figure 51. 2400 in³ airgun array 90% pulse duration (left) and rms SPL (right) in the broadside direction as a function of range at the nearshore site.

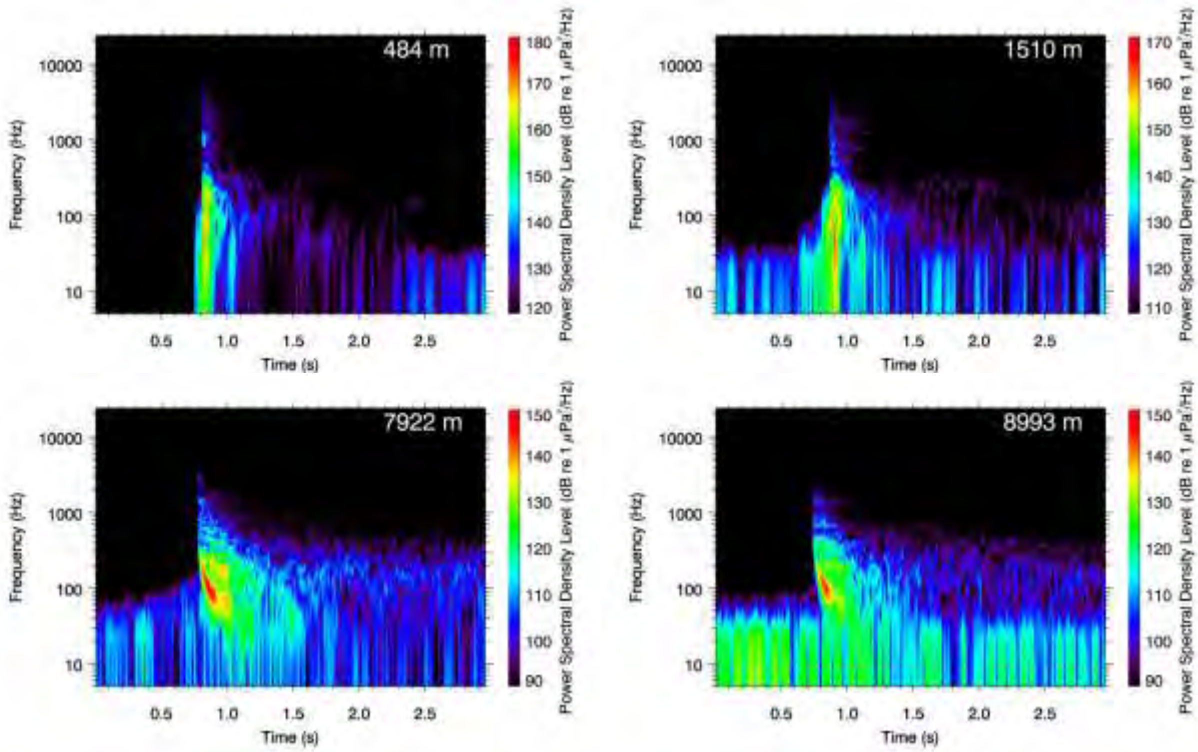


Figure 52. Spectrograms of airgun pulses from the 2400 in³ airgun array at various distances in the endfire direction at the nearshore site. 2048-pt FFT, 48 kHz sample rate, Hanning window.

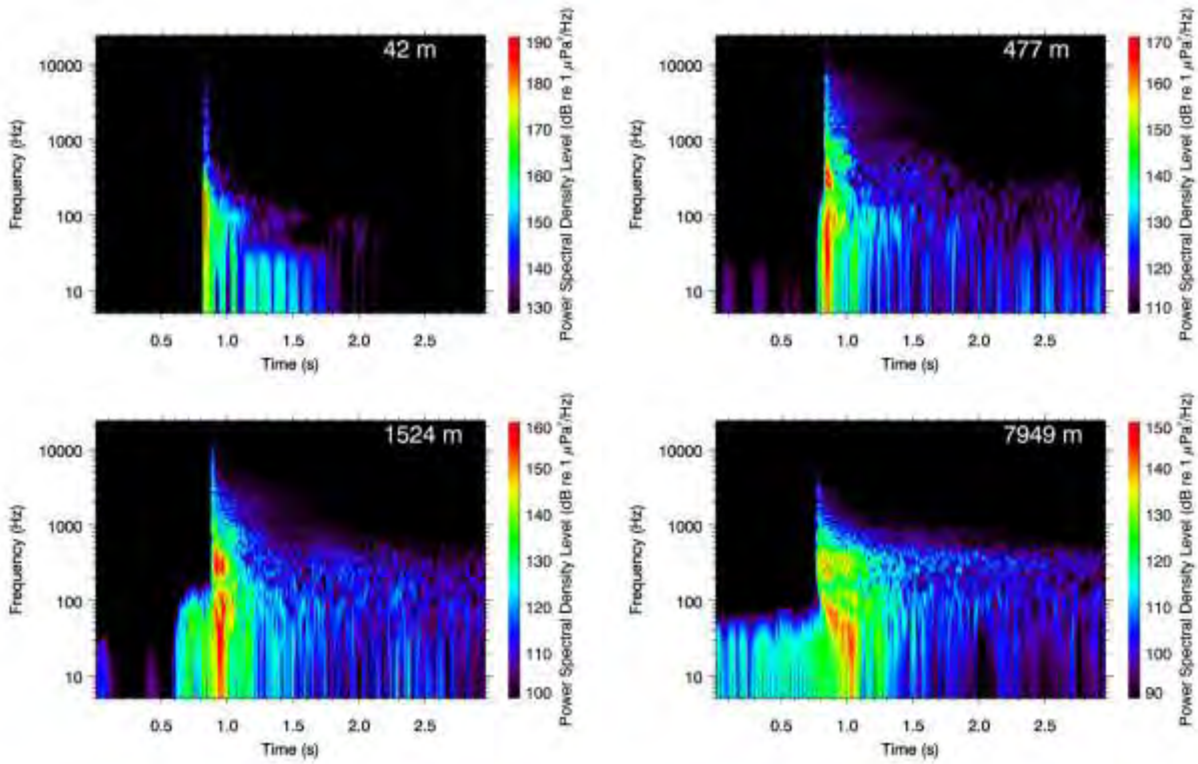
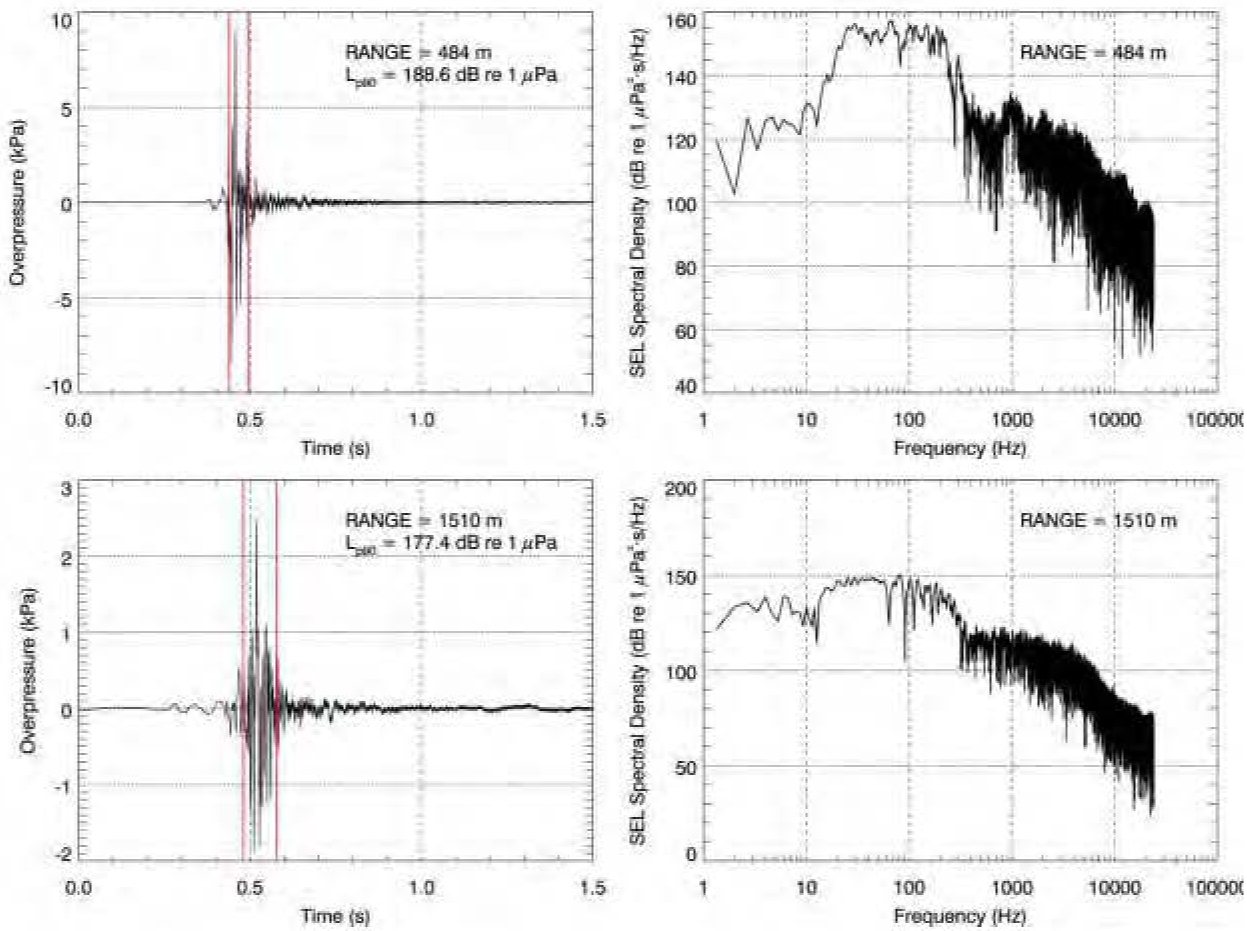


Figure 53. Spectrograms of airgun pulses from the 2400 in³ airgun array at various distances in the broadside direction at the nearshore site. 2048-pt FFT, 48 kHz sample rate, Hanning window.


RANGE = 484 m
L_{pk0} = 188.6 dB re 1 μPa
Overpressure (kPa)
Time (s)
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)
RANGE = 484 m
RANGE = 1510 m
L_{pk0} = 177.4 dB re 1 μPa
Overpressure (kPa)
Time (s)
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)
RANGE = 1510 m

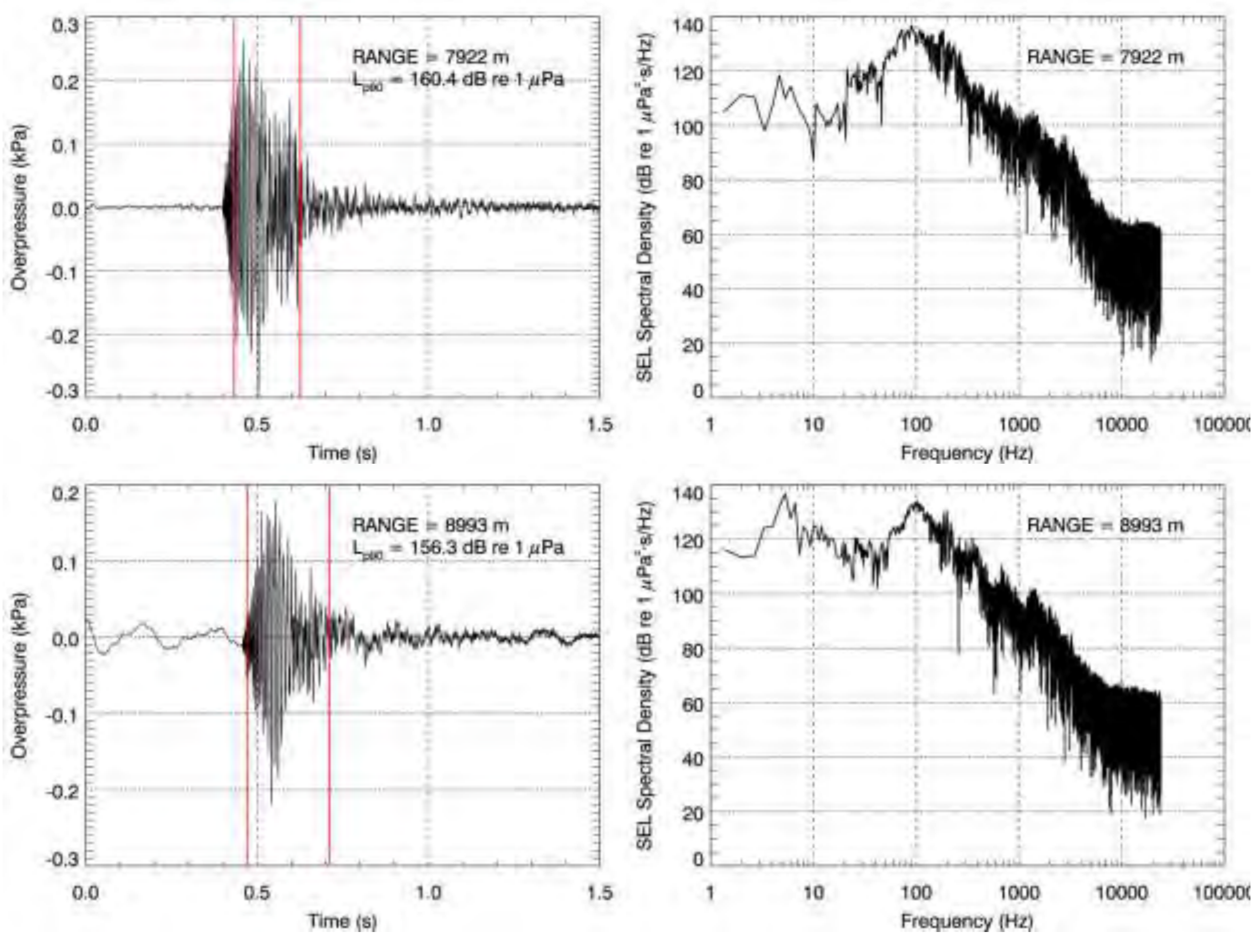
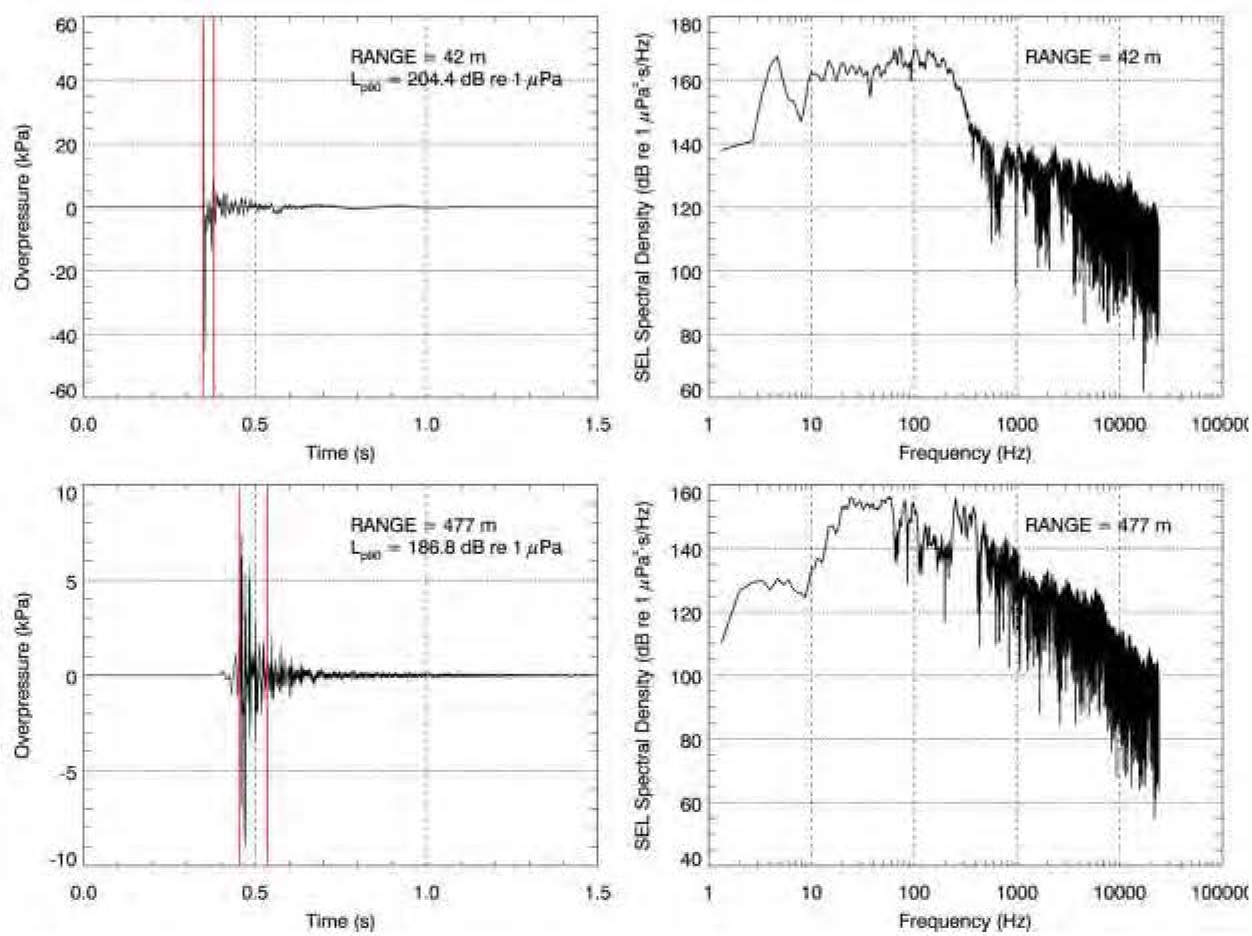


Figure 54. Waveform (left) and corresponding SEL spectral density (right) plots of 2400 in³ airgun array pulses at various distances in the endfire direction at the nearshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.


RANGE = 42 m
L_{pk0} = 204.4 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 42 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)
RANGE = 477 m
L_{pk0} = 186.8 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 477 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)

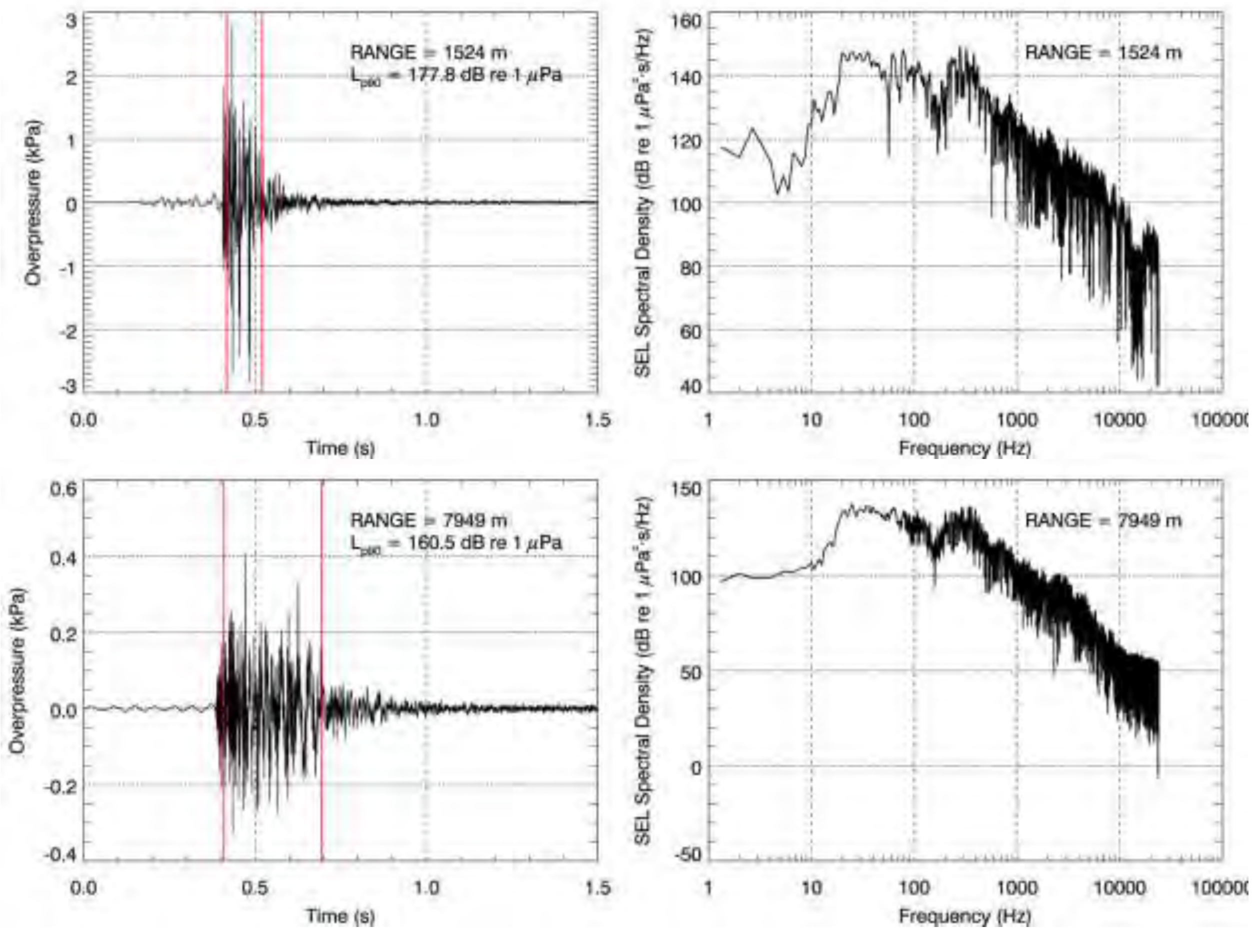


Figure 55. Waveform (left) and corresponding SEL spectral density (right) plots of 2400 in³ airgun array pulses at various distances in the broadside direction at the nearshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.

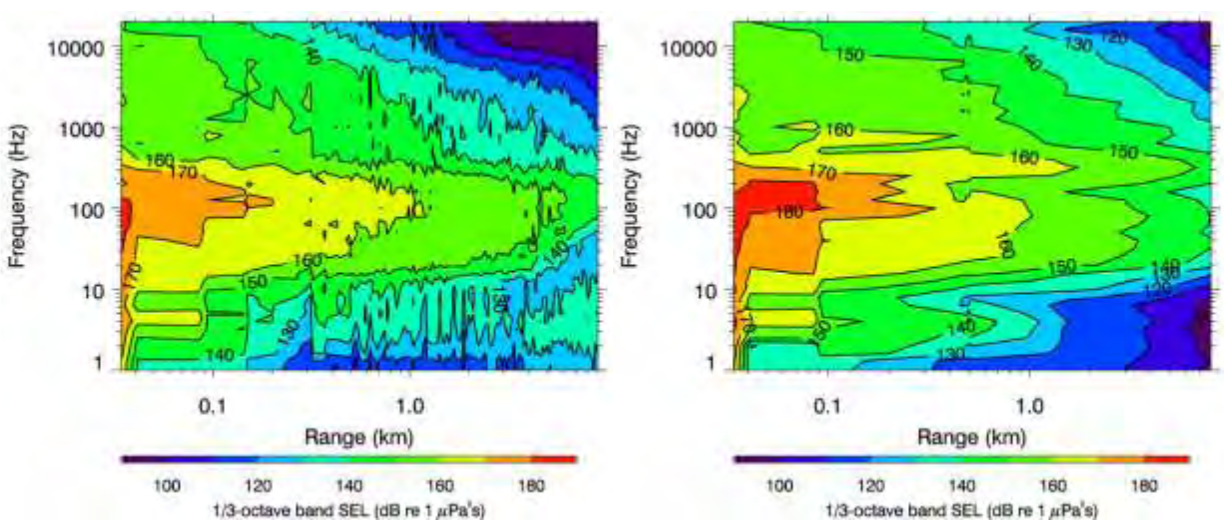


Figure 56. 1/3 octave band SEL levels as a function of range and frequency for the 2400 in³ airgun array in the endfire (left) and broadside (right) directions at the nearshore site.

4.4.2. Track 2

Peak SPL, 90% rms SPL and SEL for each shot on the offshore line were computed from acoustic data recorded on OBHs E-H. Figure 57 shows sound levels from the 2400 in³ airgun array versus slant range measured in the endfire and broadside directions. 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. Table 11 lists ranges to several rms SPL thresholds for each of the fits in Figure 57. 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 in the endfire direction 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. Figures Figure 58 and Figure 59 illustrate how rms pulse duration varied with range in the endfire and broadside directions, with the rms SPL for comparison. Figure 60 presents spectrograms of 2400 in³ airgun array pulses in the endfire direction at 613 m, 1554 m, 5525 m, and 8699 m. Pulses in the broadside direction near CPA at 43 m, 592 m, 1584 m, and 5528 m are shown in Figure 61. Figures Figure 62 and Figure 63 show waveforms and SEL spectral density plots of these same endfire and broadside pulses, respectively. Contour plots of 1/3-octave band levels versus range and frequency are shown in Figure 64. Sound levels near the source were highest between 30 and 300 Hz in the endfire direction and between 20 and 300 Hz in the broadside direction.

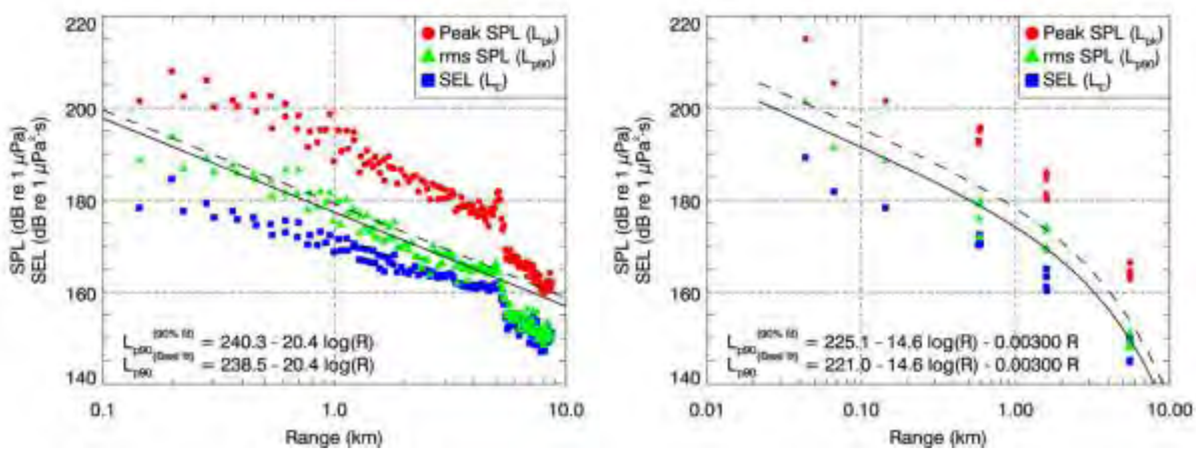


Figure 57: Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 2400 in^3 airgun array pulses in the endfire (left) and broadside (right) directions measured at the offshore site (Track 2). Solid line is best fit of the empirical function to SPL_{rms90} values. Dashed line is 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 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 57.

SPL_{rms90} Threshold (dB re 1 µPa)	Range (m) in endfire direction Best fit	90th percentile fit	Range (m) in broadside direction Best fit	90th 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

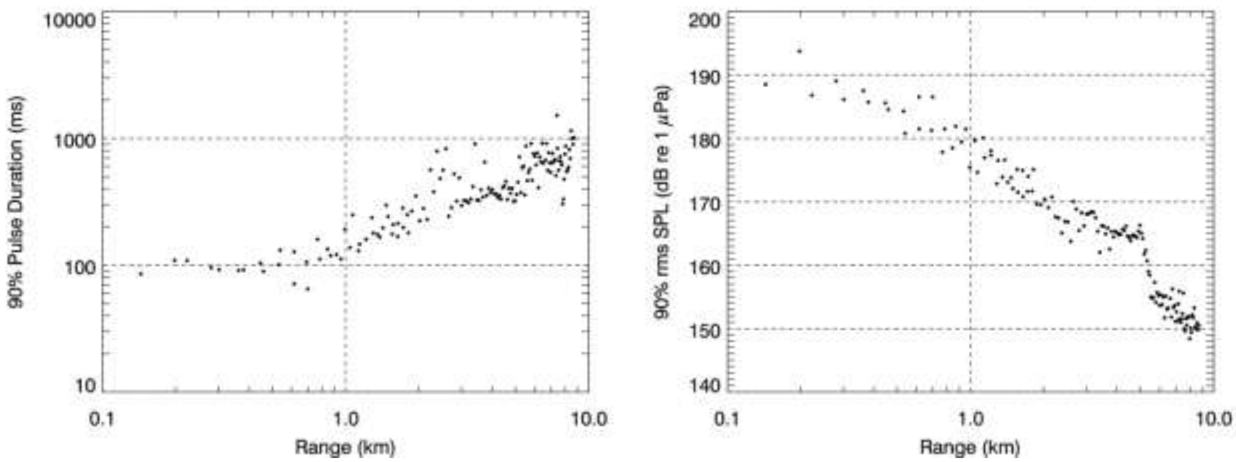


Figure 58. 2400 in³ airgun array 90% pulse duration (left) and rms SPL (right) in the endfire direction as a function of range at the offshore site.

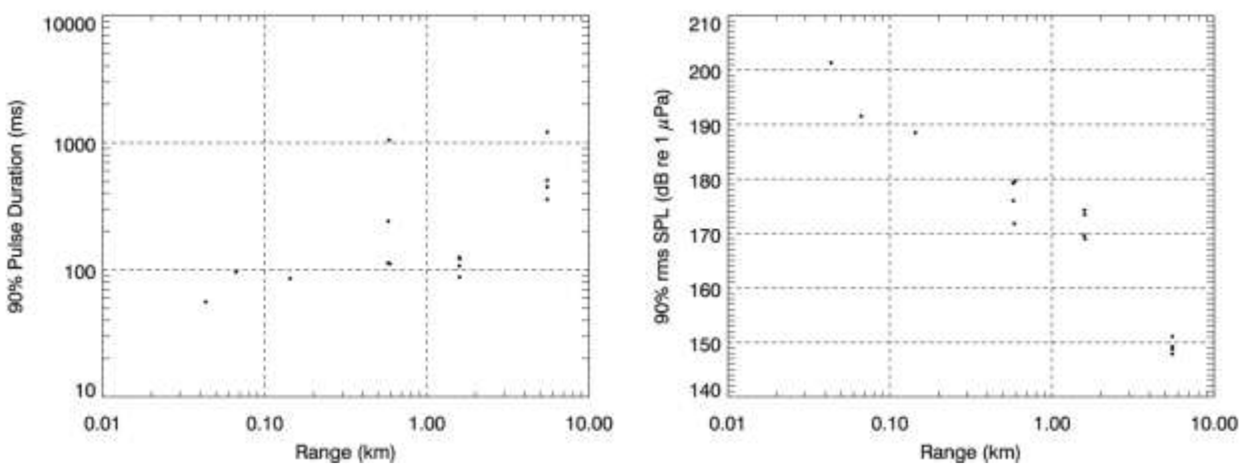


Figure 59. 2400 in³ airgun array 90% pulse duration (left) and rms SPL (right) in the broadside direction as a function of range at the offshore site.

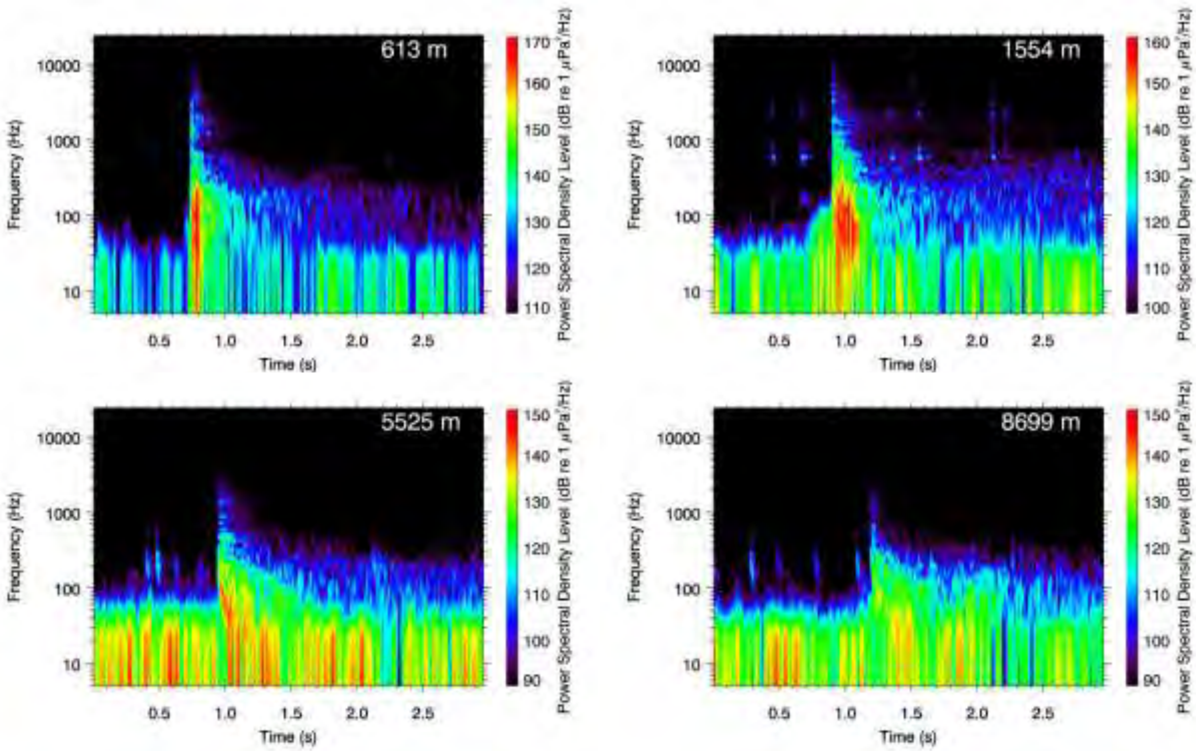


Figure 60. Spectrograms of airgun pulses from the 2400 in³ airgun array at various distances in the endfire direction at the offshore site. 4096-pt FFT, 96 kHz sample rate, Hanning window.

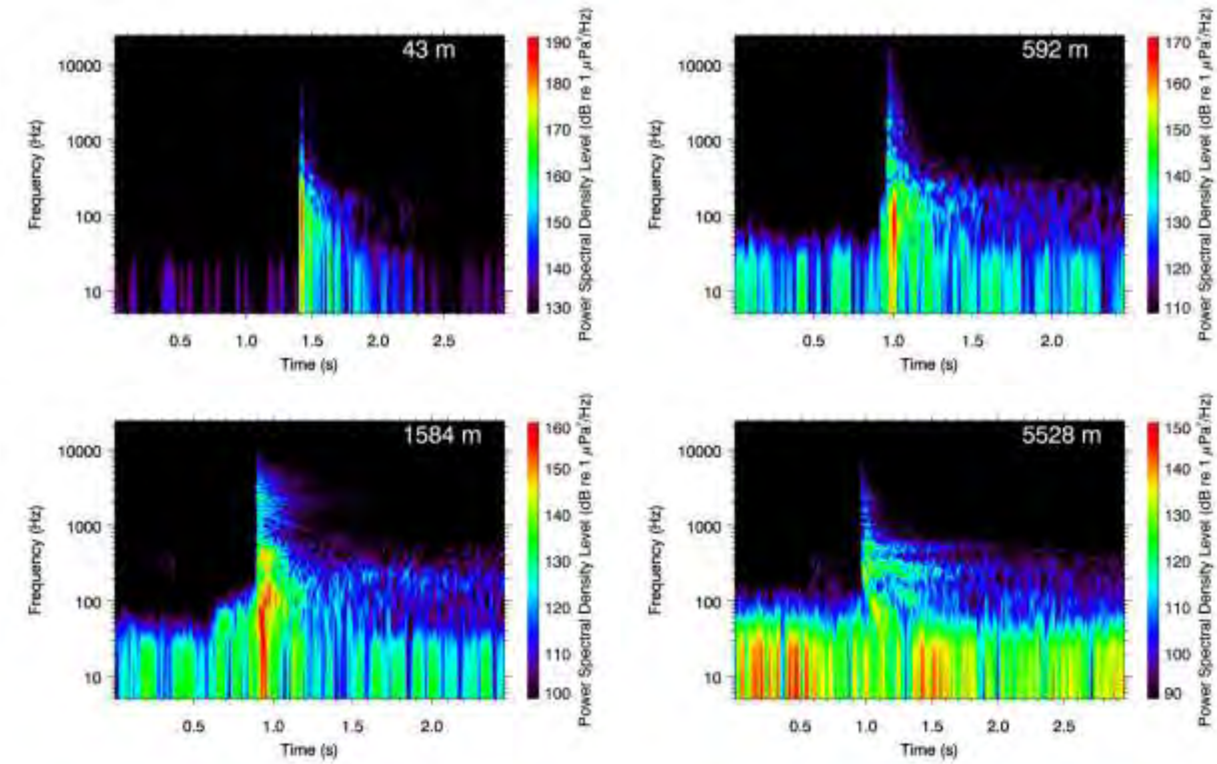
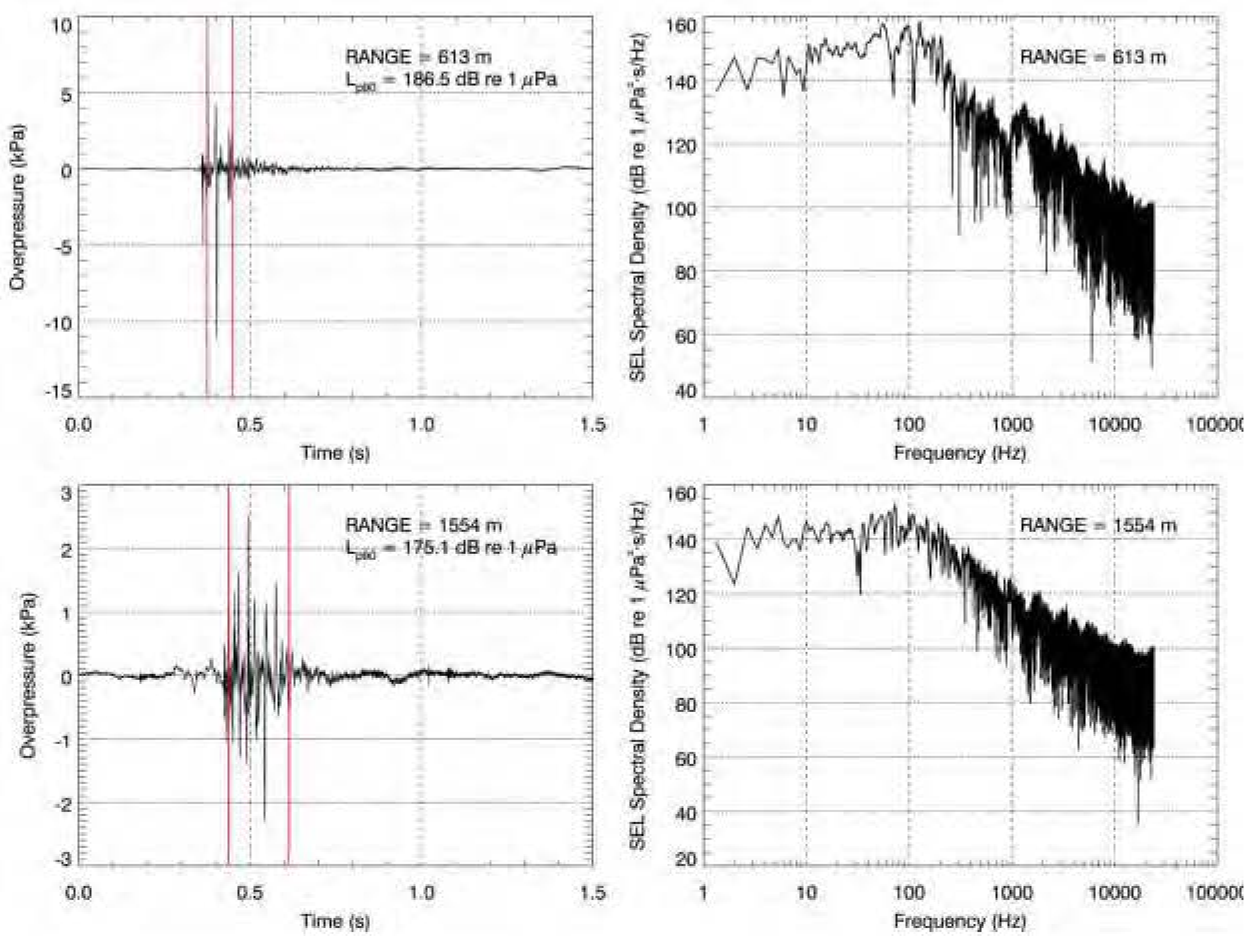


Figure 61. Spectrograms of airgun pulses from the 2400 in³ airgun array at various distances in the broadside direction at the offshore site. 4096-pt FFT, 96 kHz sample rate, Hanning window (5528 m spectrogram is 2048-pt FFT, 48 kHz sample rate).


RANGE = 613 m
L_{pk0} = 186.5 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 613 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)
RANGE = 1554 m
L_{pk0} = 175.1 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 1554 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)

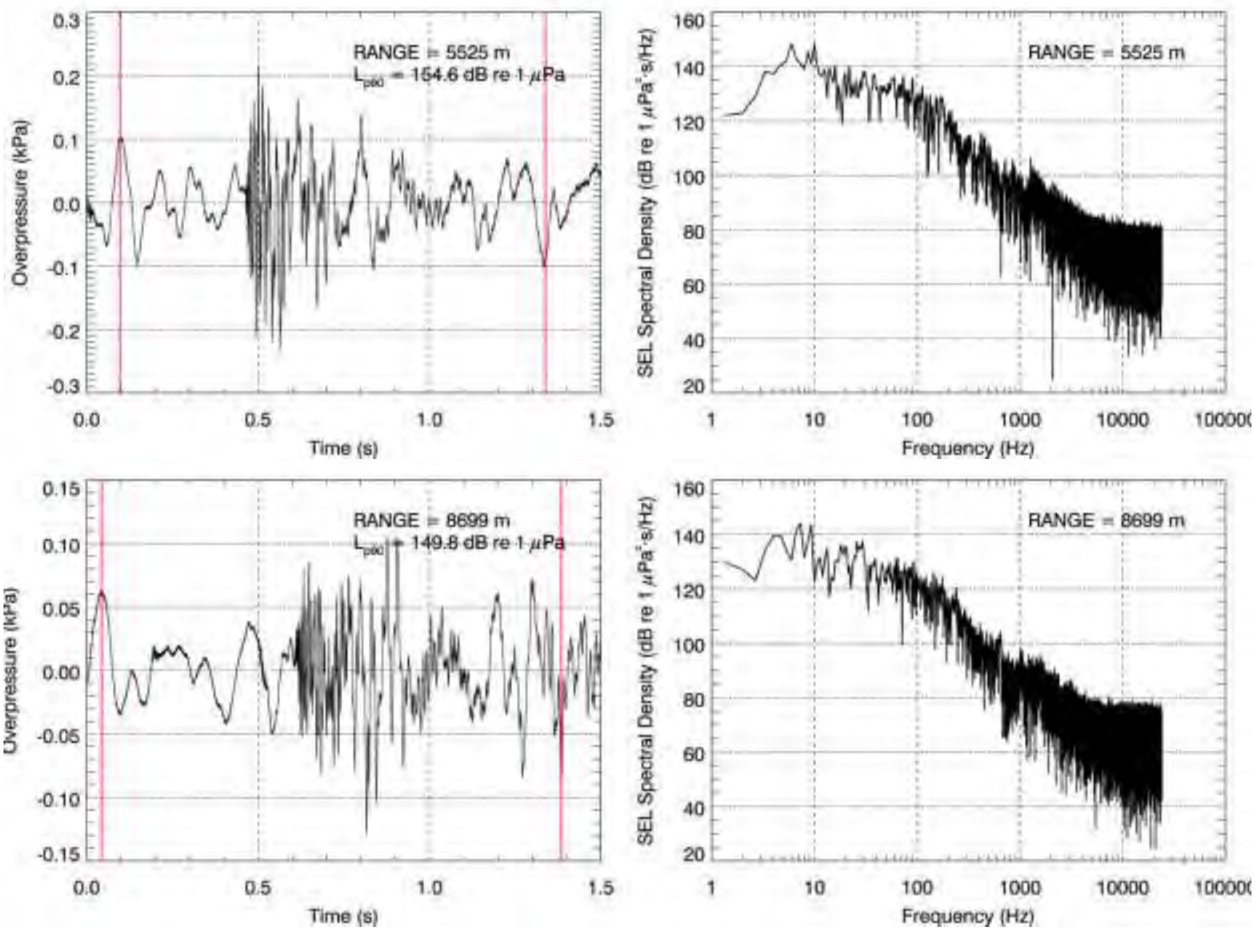
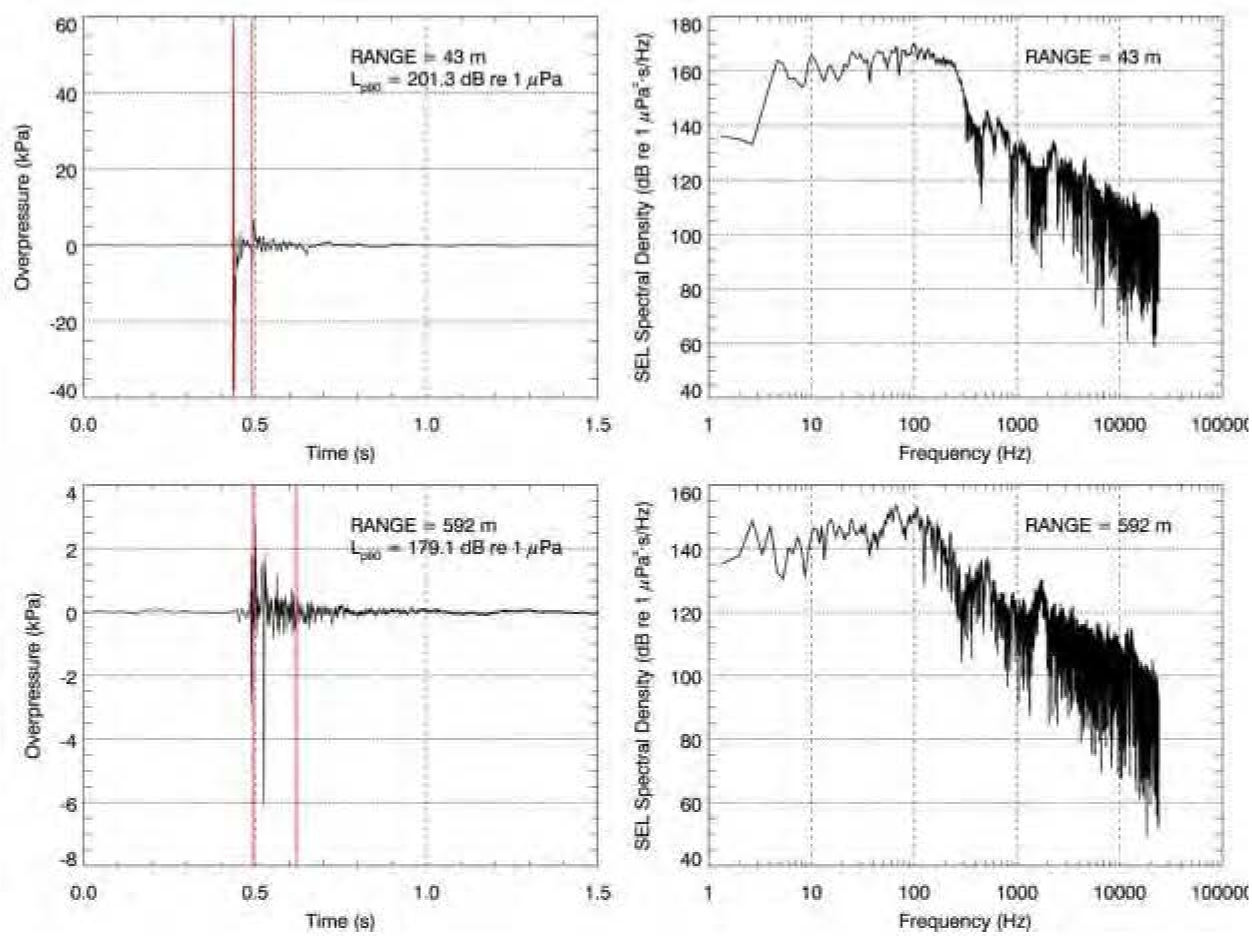


Figure 62. Waveform (left) and corresponding SEL spectral density (right) plots of 2400 in³ airgun array pulses at various distances in the endfire direction at the offshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.


RANGE = 43 m
L_{pk0} = 201.3 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 43 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)
RANGE = 592 m
L_{pk0} = 179.1 dB re 1 μPa
Overpressure (kPa)
Time (s)
RANGE = 592 m
SEL Spectral Density (dB re 1 μPa²·s/Hz)
Frequency (Hz)

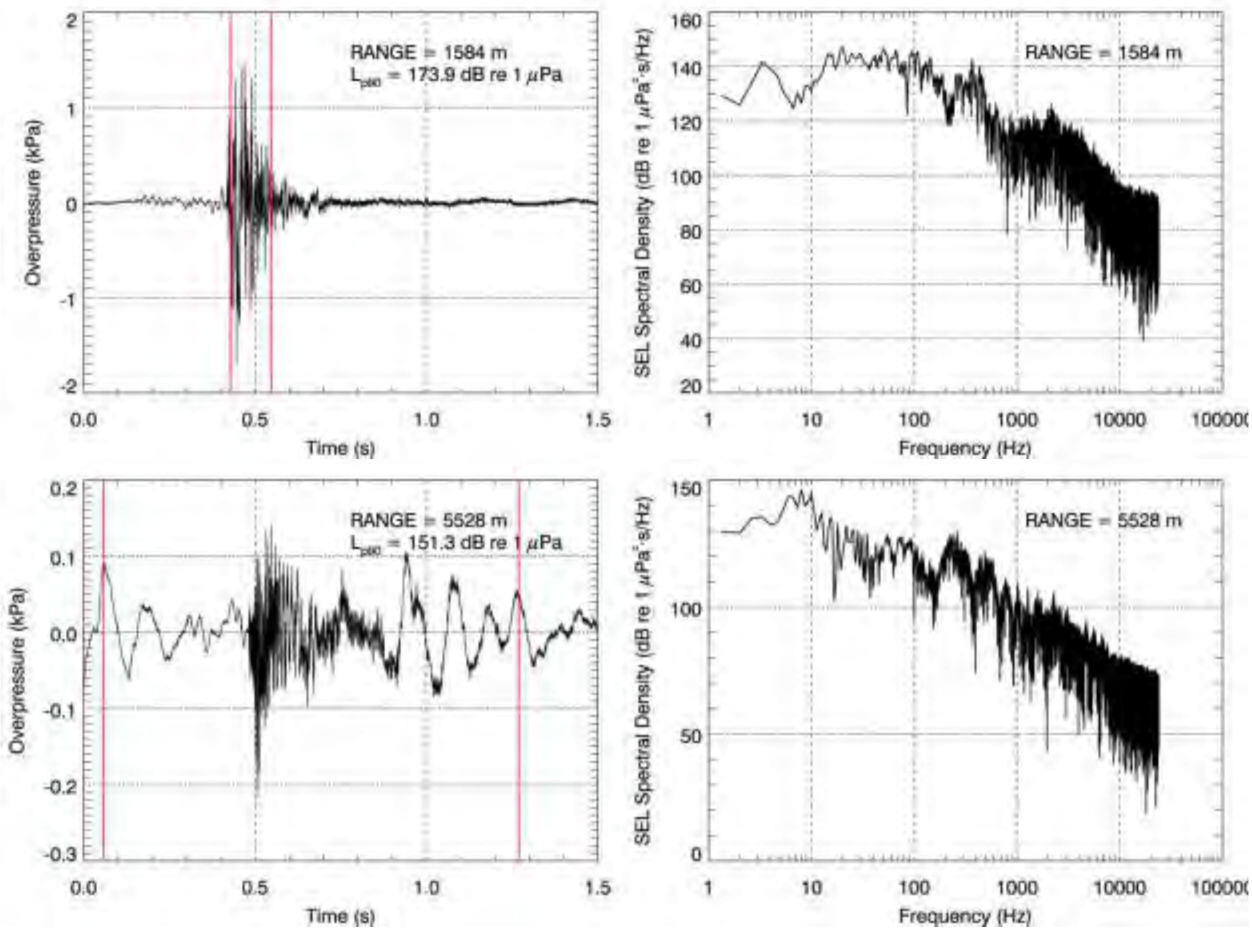


Figure 63. Waveform (left) and corresponding SEL spectral density (right) plots of 2400 in³ airgun array pulses at various distances in the broadside direction at the offshore site. The red bars on the waveform plot indicate the 90% energy pulse duration.

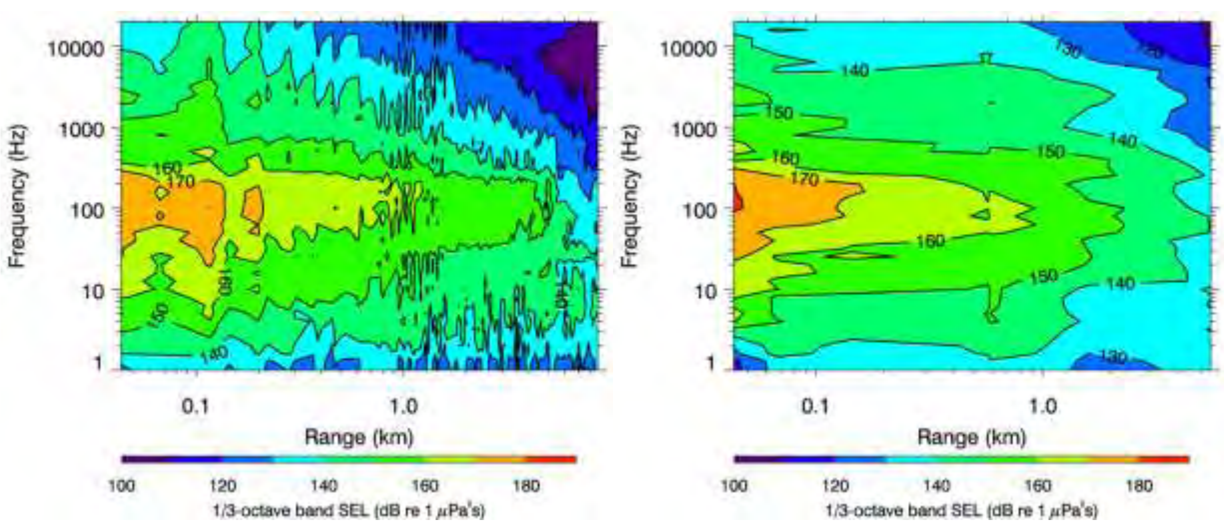


Figure 64. 1/3 octave band SEL levels as a function of range and frequency for the 2400 in³ airgun array in the endfire (left) and broadside (right) directions at the offshore site.

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.

	Safety Radii (m)				
SPL_{rms90} Threshold (dB re 1 µPa)	Pre-season Estimated	90^{th} Percentile Measured Nearshore	90^{th} 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.

	Safety Radii		
SPL_{rms90} Threshold (dB re 1 µPa)	Pre-season Estimated (from IHA)	90^{th} 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.

	Safety Radii		
SPL_{rms90} Threshold (dB re 1 µPa)	Pre-season Estimated (from IHA)	90^{th} 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 90^{th} 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 in^3 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 in^3 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.

Warner, G., J. Wladichuk and D.E. Hannay. *Sound Source Acoustic Measurements for Apache's 2012 Cook Inlet Seismic Survey*: Version 2.0. Technical report for Fairweather LLC by JASCO Applied Sciences. June 3, 2011.

APPENDIX C

JASCO Hydroacoustic Modeling of Airgun Noise for Apache's Cook Inlet Seismic Program

Hydroacoustic Modeling of Airgun Noise for Apache's Cook Inlet Seismic Program

24-Hour Harassment Area Calculations

Submitted to:
NES-LLC

Authors:
Graham Warner
Jennifer Wladichuk
David Hannay

2011 June 15

P001134-004
Version 1.0

JASCO Applied Sciences
Suite 2101, 4464 Markham St.
Victoria, BC, V8Z 7X8, Canada
Phone: +1.250.483.3300
Fax: +1.250.483.3301
www.jasco.com

Suggested citation:

Warner, G., J. Wladichuk and D.E. Hannay. *Hydroacoustic Modeling of Airgun Noise for Apache's Cook Inlet Seismic Program*: *24-Hour Harassment Area Calculations* Version 1.0. Technical report for NES-LLC by JASCO Applied Sciences. June 3, 2011.

Contents

Tables

Figures

1. Introduction

This acoustic modeling study has been performed to estimate underwater sound levels produced by airgun array systems of Apache's planned Cook Inlet seismic surveys. Sound from airgun arrays has the potential to harass nearby marine mammals. The National Marine Fisheries Service (NMFS) presently considers exposures of marine mammals to impulsive airgun sound levels above 160 dB re 1 µPa (rms) to cause harassment. Exposures above this threshold are considered level-B takes by NMFS (in contrast to level-A takes which refer to injury). Level-B takes generally need to be permitted under Incidental Harassment Authorizations (IHA). Apache will apply for an IHA for their seismic programs and consequently needs to estimate the number of takes for several species. The number of acoustic takes for each species is calculated by multiplying the area ensonified above 160 dB re 1 µPa (rms), by the spatial density of that species. The modeling work performed here estimates the areas needed to calculate the take numbers to be requested in the IHA application.

This report describes the methods and computer models used to predict noise levels. It provides distances to several SPL thresholds and reports the areas ensonified above 160 dB re 1 µPa per 24-hour period of surveying in Cook Inlet for several depth environments. The predictions will be used to estimate the number of takes over the duration of Apache's seismic program.

2. Acoustic Metrics

2.1. Impulsive Noise Metrics

Impulsive or transient noise is characterized by brief acoustic events characterized by rapid pressure change at the onset of the event followed by pressure decay back to pre-existing levels within a few seconds or less. Impulsive sound levels are commonly characterized using three acoustic metrics: peak pressure, rms pressure or sound pressure level (SPL), and sound exposure level (SEL). The peak pressure (symbol L_{Pk}) is the maximum instantaneous absolute sound pressure level measured over the impulse duration:

$$L_{Pk} = 20\log_{10}\left(\max\left|p(t)\right| / P_{ref}\right) \tag{1}$$

In this formula, $p(t)$ is the instantaneous sound pressure as a function of time t, measured over the impulse duration $0 \leq t \leq T$. This metric is very commonly quoted for impulsive sounds but does not take into account the duration or bandwidth of the noise.

The rms sound pressure level may be measured over the impulse duration according to the following equation:

$$L_P = 10\log_{10}\left(\frac{1}{T}\int_T p(t)^2\,dt / P_{ref}^2\right) \tag{2}$$

In practice the beginning and end times of an impulse can be difficult to identify precisely. In studies of underwater impulsive noise, T is often taken to be the interval over which the cumulative per-pulse SEL (see following discussion) rises from 5% to 95% of the total pulse SEL. This interval, (T_{90}), contains 90% of the total SEL and the SPL computed over this interval is therefore referred to as the 90% rms SPL (L_{P90}). Figure 1 shows an example of an impulsive noise pressure waveform, with the corresponding peak pressure, rms pressure, and 90% time interval.

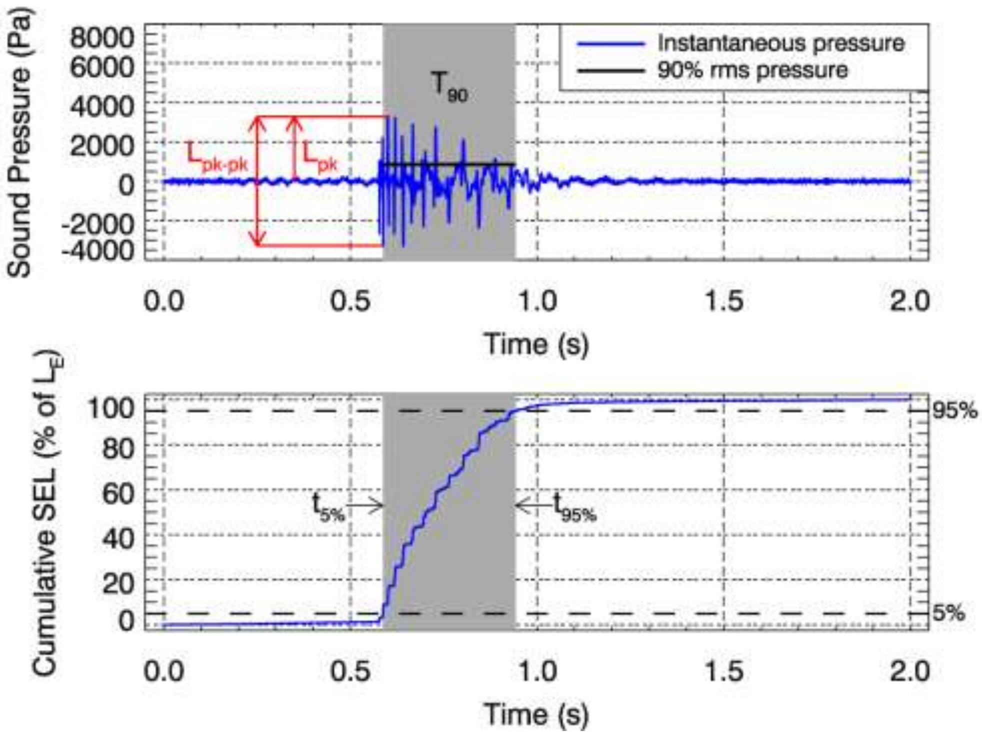


Figure 1. Example waveform (top) and cumulative SEL (bottom) for an impulsive noise measurement. The peak and peak-to-peak levels are annotated on the waveform plot and the 90% rms SPL is indicated with a black line. The gray area indicates the 90% time interval (T_{90}) over which the rms pressure is computed.

The sound exposure level or SEL (symbol L_E) is a measure related to the sound energy flux density of one or more impulses, but it does not account for impedance of the propagating medium and it is not measured in energy density units. The SEL for a single impulse is computed from the time-integral of the squared pressure over the impulse duration:

$$L_E = 10\log_{10}\left(\int_{T_{100}} p(t)^2\, dt / P_{ref}^2\right) \tag{3}$$

Sound exposure levels for impulsive noise sources (i.e. airgun impulses) presented in this report refer to single pulse SELs.

Because the 90% rms SPL and SEL for a single impulse are both computed from the integral of square pressure, these metrics are related by a simple expression that depends only on the duration of the 90% time window T_{90}:

$$L_E = L_{P90} + 10\log_{10}(T_{90}) + 0.458 \tag{4}$$

In this formula, the 0.458 dB factor accounts for the remaining 10% of the impulse SEL that is excluded from the 90% time window. In the following sections of this report, all references to rms levels refer to the 90% rms SPL metric.

Finally, the SPL and SEL metrics are sometimes calculated from a pressure signal that has been first passed through frequency filters. The filters are designed to account for frequency-dependent hearing sensitivity of the species exposed to the sound. If filtering is applied then the SPL and SEL levels are described as frequency-weighted. Several standard filters are used, including filters designed for marine mammal hearing, but these are not currently considered by NMFS for Cook Inlet effects assessment. A good discussion of filtering approaches for marine mammals is given in a recent report that describes methods for noise effects assessments based on frequency-weighted SEL (Southall *et. al*., 2007).

3. Methods

3.1. Sound Propagation Model

The acoustic propagation model used for this study was JASCO's Marine Operations Noise Model. MONM computes the received sound pressure level from noise sources such as airguns and vessels. MONM treats sound propagation in range-varying acoustic environments through a wide-angled parabolic equation (PE) solution to the acoustic wave equation. The PE code used by MONM is based on a version of the Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for shear wave losses due to reflections from elastic seabeds. The PE method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins, 1993).

MONM accounts for depth and/or range dependence of several environmental parameters including bathymetry and sound speed profiles in the water column and the sea floor. It also accounts for the additional reflection loss that is due to partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces. It includes wave attenuations in all layers. The acoustic environment is sampled at a fixed range step along traverses.

Full waveform pressure-time series predictions were computed using MONM in full wave mode. In this mode, MONM computes pressure waveforms via Fourier synthesis of the modeled acoustic transfer function in closely spaced frequency bands between 10 and 2048 Hz. This frequency range includes the important bandwidth of noise emissions for the airgun array considered here. Range-dependent impulse-response functions were modeled between these frequencies in 1 Hz steps and convolved with the far-field source signature of the airgun array to generate synthetic pressure waveforms along each transect. These waveforms were then analyzed to determine the rms SPL as a function of range from the source. MONM's sound level predictions have been validated against other models and experimental data (Hannay & Racca, 2005).

3.2. Acoustic Source Levels of the Airgun Array

The acoustic source level of the 2400 in^3 airgun array was predicted using JASCO's airgun array source model (AASM). AASM simulates the expansion and oscillation of the air bubbles generated by each airgun within a seismic array, taking into account pressure interaction effects between bubbles from different airguns. It includes effects from surface-reflected pressure waves, heat transfer from the bubbles to the surrounding water, and the movements of bubbles due to their buoyancy. The model outputs high-resolution airgun pressure signatures for each airgun. These signatures are superimposed with the appropriate time delays to yield the overall array source signature in any direction.

The array geometry is shown in Figure 2. The array consists of 16 individual guns with individual volumes of 150 in^3 arranged in clustered pairs. The overall layout is comprised of two sub-arrays of 8 guns each. Only 12 airguns are shown in the figure below because each sub-array contains a pair of airguns suspended below the middle pairs (and hence not visible in this plan view).

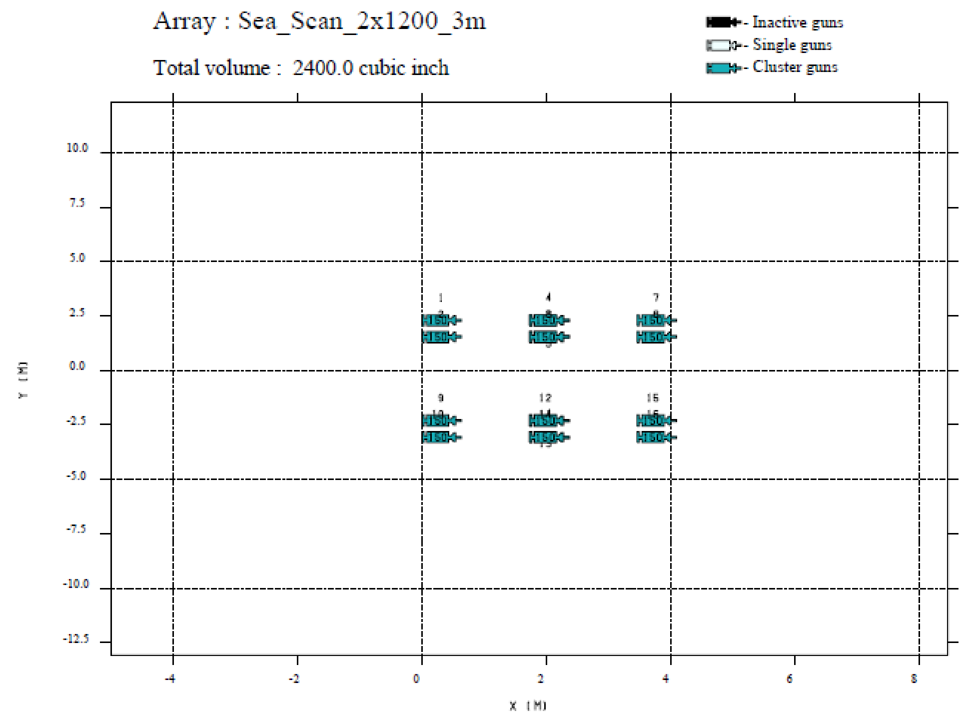


Figure 2: Geometry layout of 2400 in^3 array. Tow direction is to the right; tow depth is 3.0 m; the volume of each airgun is indicated in cubic inches.

The airgun array is expected to be operated at a constant depth of 3 m during the course of the survey. The modeling of the airgun array signature was carried out for a towing depth of 3 meters with a firing pressure of 2000 psi.

AASM was used to characterize the spectral and directional attributes of the array's composite pressure signature in all directions as described above. The overpressure signatures and the power spectra for the broadside (perpendicular to tow) and forward endfire (parallel to tow) directions are shown in Figure 3.

The general trend is for spectral levels to decrease with increasing frequency, and most of the airgun energy is contained in frequencies below 500 Hz. To calculate the source directivity, the far-field array signature was filtered into 1/3-octave pass bands. Source directivity is insignificant below 100 Hz but it becomes prominent at higher frequencies. The horizontal directivity of the array as a function of frequency is presented in Figure 4. In these plots, the arrow indicates the tow direction of the array and the solid black curves indicate sound exposure level in dB re 1 μPa^{2}s at 1 m as a function of angle in the horizontal plane. These levels are not directly used by MONM in full waveform mode; they are included here only to illustrate the horizontal directivity pattern of the array. MONM inherently treats vertical and horizontal directivity in full-wave mode.

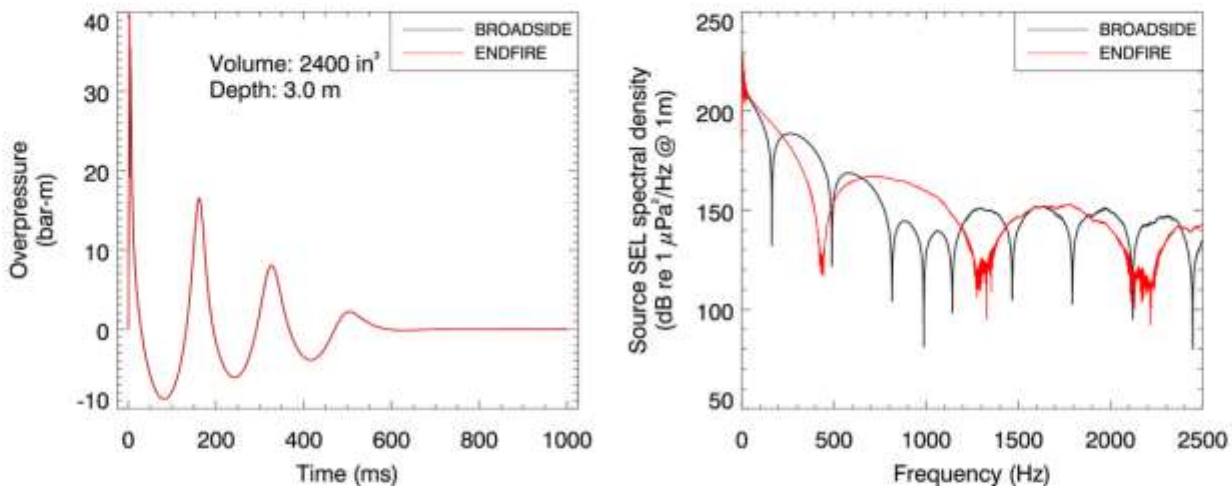


Figure 3: Overpressure signature and power spectrum for the 2400 in^3 array in the broadside and endfire directions. Surface ghosts are not included in these signatures.

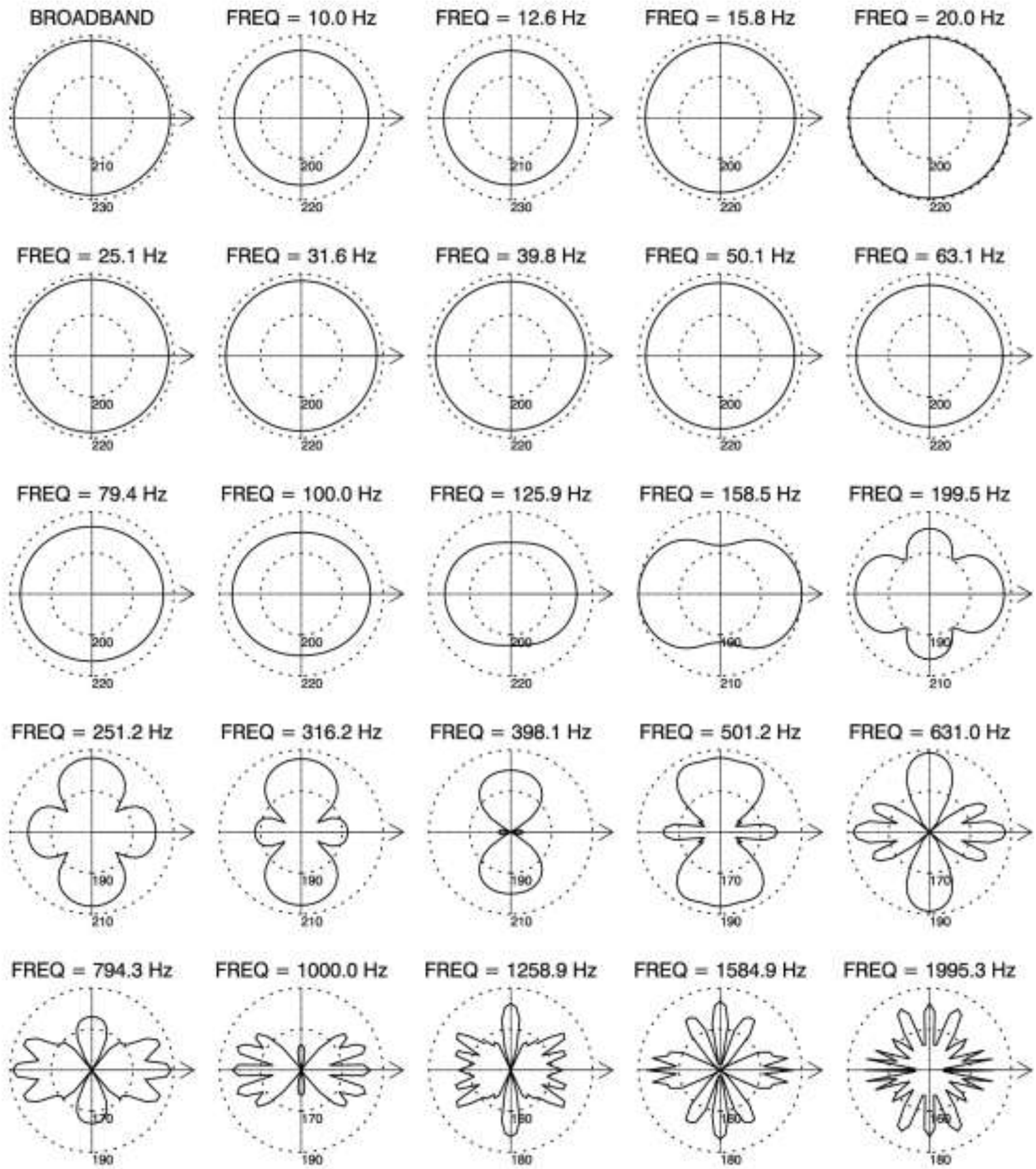


Figure 4: Azimuthal directivity patterns of the seismic array source levels (dB re 1 μPa^2 s at 1 m) for the 2400 in^3 array towed at 3 m depth, in 1/3-octave bands, by center frequency.

3.3. Acoustic Environment

3.3.1. Bathymetry

The acoustic models use high-resolution grids of bathymetry to define water depths inside a region of interest. Apache plans to survey many prospects in Cook Inlet over the duration of their surveys and the precise locations and sequence of prospects to be surveyed are presently unknown. However, the general bathymetry along the inlet is relatively uniform and consequently representative environments can be defined that are relevant for multiple survey locations.

Two general survey environment scenarios were considered for this modeling study: a nearshore survey scenario (from shore out to 18 km offshore) and a channel survey scenario (more than 18 km from each shore). The nearshore scenario was further divided into 3 distance intervals of 6 km each from shore, with this interval defined by the zone that can be surveyed in a 24 hour period based on an anticipated survey line length and line spacings that are discussed later.

Water depths for the nearshore scenario increase by 25 m per 10 km distance away from shore. The depth of the channel scenario has constant depth of 80 m, which is the approximate median depth along the center of the Cook Inlet's channel.

3.3.2. Underwater sound speed

The sound velocity profile (SVP) used in the acoustic model was derived from conductivity-temperature-depth (CTD) surveys conducted within the project test area in Cook Inlet between 25 March and 1 April 2011. The CTD data reveal a fairly uniform sound speed with depth for all fourteen casts conducted (typically < 2 m/s variation) (see Figure 5), with a mean value of 1436 m/s across all depths.

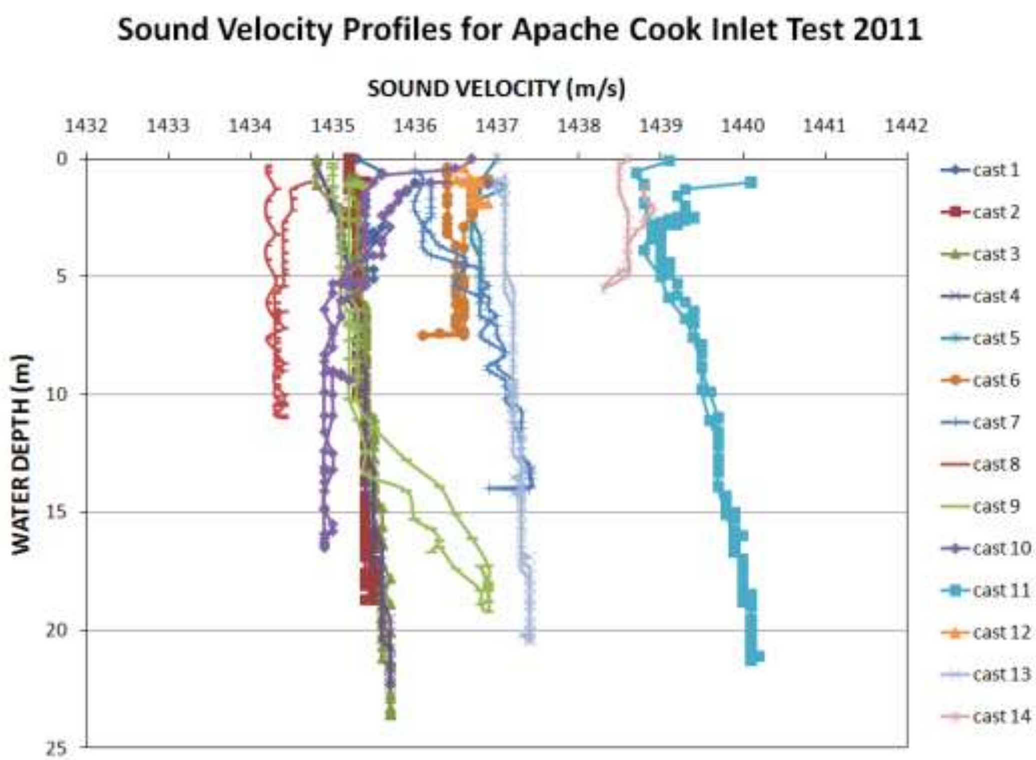


Figure 5: Sound velocity profiles as derived from CTD cast measurements obtained between 25 March and 1 April 2011 in Cook Inlet, Alaska.

Variability in sound velocity profile shape can exist with time of year due to seasonal temperature and salinity cycles. Therefore, a review of two other sources of SVP data for Cook Inlet was done to confirm the validity of this observed iso-velocity SVP shape and mean value.

Sound velocity profiles were examined for each month of the year using the US Naval Oceanographic Office's Generalized Digital Environmental Model (Teague *et al.*1990) database for a location in the middle of Cook Inlet. The other source of SVP is from field work conducted in April 2007 (JASCO). The data from these two sources concurs with the SVP from the 2011 measurements, and thus a constant sound velocity of 1436 m/s was used in the acoustic model.

3.3.3. Seabed geoacoustics

The geoacoustic profile for Cook Inlet, describing the elasto-acoustic properties of the seabed sediments, was first estimated from a geological profile at the Port of Anchorage (Hashash, 2008). The engineered fill and Bootlegger Cove formation layers were disregarded as they would not be present in the majority of Cook Inlet. The resulting profile consisted of a surface layer of sand, silt, and clay, overlaying glacial-fluvial sands, gravels, and glacial till. Descriptions of soil composition for these layers were used to estimate geoacoustic properties, using the methods described by Hamilton (1980).

The five geoacoustic layer properties considered by the sound propagation model for sub-bottom sediments are as follows:

1. Relative density: The density of the bottom materials relative to the density of water.
2. Compressional-wave sound speed: The phase speed of longitudinal body waves (P-waves) in the bottom materials (units of m/s).
3. Compressional attenuation: The rate of attenuation (units of dB per wavelength) of longitudinal body waves in the bottom materials.
4. Shear-wave sound speed: The phase speed of transverse body waves (S-waves) in the bottom materials (units of m/s).
5. Shear attenuation: The rate of attenuation (units of dB per wavelength) of transverse body waves in the bottom materials.

MONM accepts profiles of density, compressional-wave speed, and compressional attenuation defined to arbitrary depth in the bottom. Reflection losses at the seabed, caused by partial conversion of compressional waves to shear waves at each layer interface, are accounted for in MONM using a complex-density approximation.

In order to ensure that the derived geoacoustic parameters were appropriate for Cook Inlet, MONM was run to model sound levels from the 880 in^3 array used in the ConocoPhillips 2007 survey (JASCO, 2007). The modeled peak, rms, and SEL values were compared to measured data and the compressional sound speed at the seabed was adjusted until an optimal fit between the modeled and measured levels was obtained. The resulting geoacoustic profile, intended to represent mean sediment properties over Cook Inlet, is presented in the table below.

Table 1: Seabed geoacoustic profile for Cook Inlet. Geoacoustic parameters are based on the soils containing a mixture of sands, silts, and clays transitioning to glacial-fluvial sands, gravels, and glacial till with depth.

Depth (mbsf)	Density (g/cm^3)	Compressional Sound Speed (m/s)	Compressional Attenuation (dB/λ)	Shear Sound Speed (m/s)	Shear Attenuation (dB/λ)
0	1.58	1480	0.17	110	2.0
108	2.18	1844	0.50	-	-

3.4. Area of Harassment Calculation

The area ensonified to above 160 dB re 1 µPa over 24 hours of seismic surveying is dependent on the seismic survey line geometry because the zones from multiple survey lines often overlap. Apache plans to survey 12 to 14, 16.1 km long lines each day. The survey lines will be parallel to shore, separated nominally by 503 m, and immediately-adjacent lines will be surveyed sequentially. Based on this survey description, MONM was used to model sounds from the array in the two characteristic environments described in Section 3.3.1.

For the nearshore surveys, the source was modeled at three positions on the slope with water depths 5, 25, and 45 m. At each source position, three transects were modeled corresponding to the onshore, offshore, and parallel-to-shore directions. Since the airgun array will be towed parallel to shore, these directions correspond with the onshore-broadside, offshore-broadside, and endfire directions relative to the array. For the channel surveys, the source was modeled in 80 m deep water in the broadside and endfire directions.

The received levels vary with distance from the array and with receiver depth (that can be anywhere in the water column). The distances to 160 dB re 1 µPa were calculated in each direction by considering the maximum level over all possible receiver depths. We interpolated and extrapolated from the distance values modeled for the 3 different source location water depths of the nearshore scenario to obtain the 160 dB re 1 µPa distances for all source location water depths between 5 and 54 m.

The acoustic footprint for each survey line was calculated by defining encompassing rectangles formed by the distance of the 160 dB re 1 µPa threshold from the survey line, accounting for the differences in these distances for the different directions (Figure 6). The total area ensonified over the period of 24 hours was calculated from the union of 14 single survey line rectangles. Figure 7 illustrates the process for the union of just two survey line rectangles; this process was extended to all 14 lines of one day's anticipated survey production.

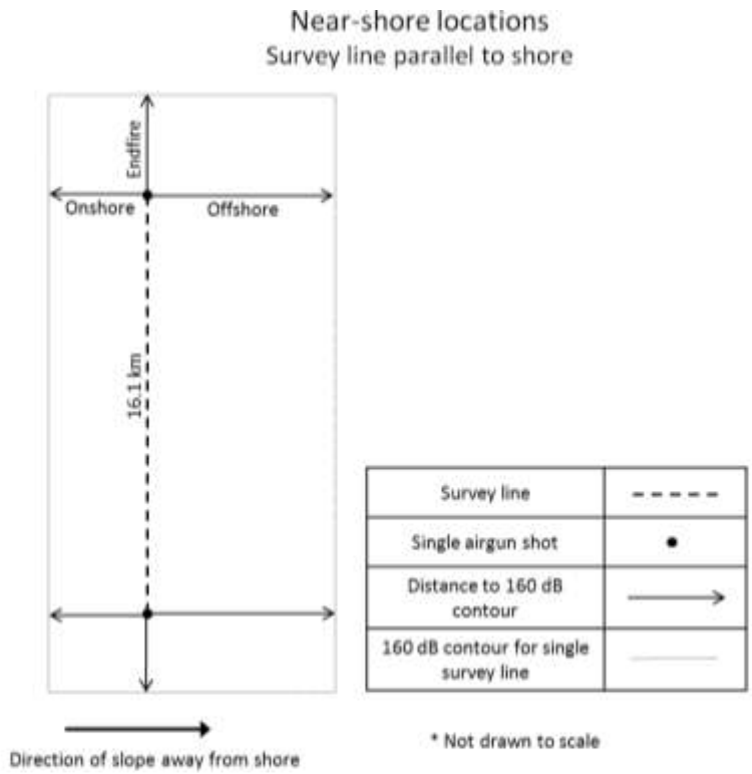


Figure 6: Diagram showing the creation of the 160 dB rectangular contour for a single survey line. In practice the corners are rounded but this has only a small reducing influence on the total areas.

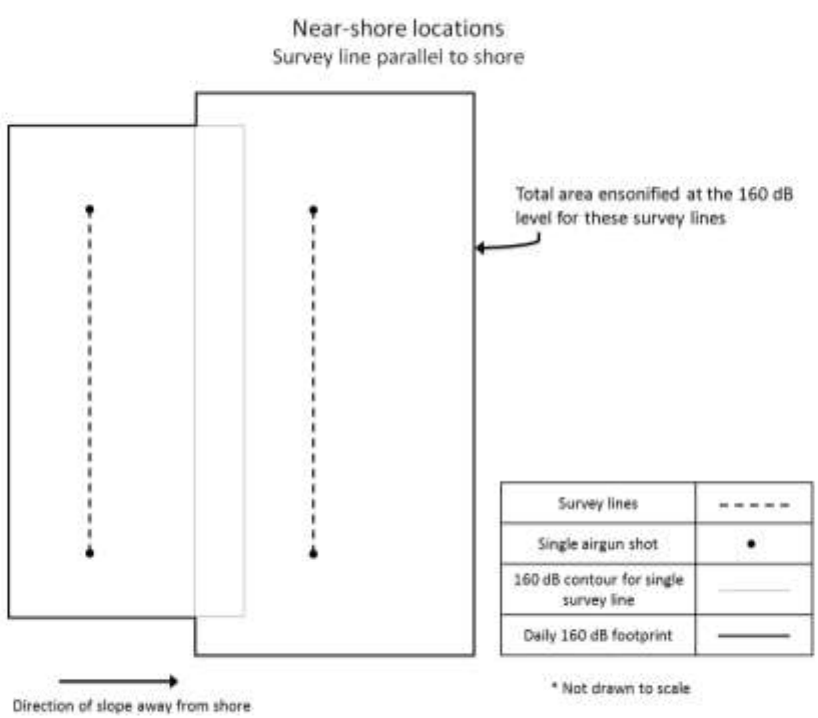


Figure 7: Diagram showing the union of two 160 dB rectangles (light grey lines) from two survey lines to get the combined 160 dB footprint (bold black line). The more offshore survey line (right) is in deeper water which supports better sound propagation. It consequently has a larger individual footprint size, hence its larger rectangle.

The daily area ensonified to 160 dB for nearshore surveys depends on the water depths of the lines surveyed. A daily survey of 14 parallel lines with 500 m spacing would span 6.5 km, corresponding to a water depth variation of about 16 m. Because the total daily footprint for nearshore surveying varies with depth, we divided the nearshore scenarios into three depth intervals, each of which could be surveyed in a single day: shallow (5-21 m), intermediate (21-38 m), and deep (38-54 m). The 24-hour ensonified areas were computed separately for each of the three nearshore survey depth intervals.

4. Model Scenarios and Results

4.1. Overview of Model Scenarios

The distances to 190, 180 and 160 dB re 1 μPa threshold for various source depths and in different directions from the source, and relative to shore, were calculated by the acoustic model. The 160 dB re 1 μPa threshold distances were calculated for the three nearshore survey depth intervals and single depth channel survey also in different directions from the source. The daily areas ensonified above the 160 dB re 1 μPa threshold were then calculated for each of the four survey depth intervals. The distance and area results are presented below.

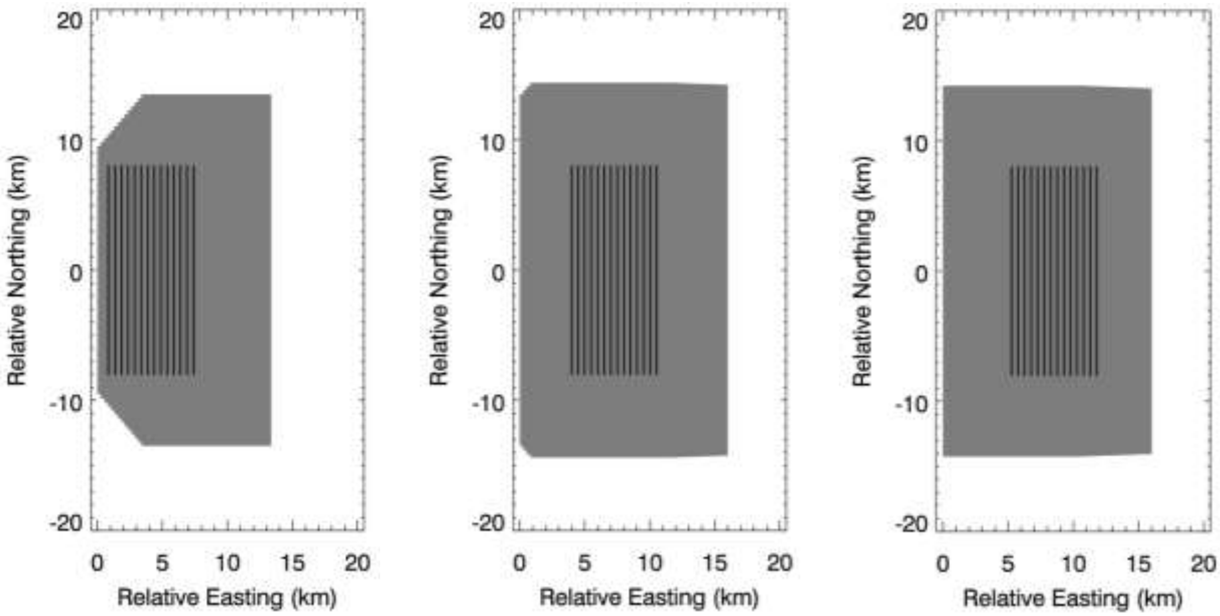
4.2. Nearshore Survey Results

The distances to the 160, 180, and 190 dB re 1 μPa sound level thresholds for the nearshore survey locations are given in Table 2. Distances correspond to the three transects modeled at each site in the onshore, offshore, and parallel to shore directions.

Table 2: Distances to sound level thresholds for the nearshore surveys.

Sound Level Threshold (dB re 1 μPa)	Water Depth at Source Location (m)	Distance in the Onshore Direction (km)	Distance in the Offshore Direction (km)	Distance in the Parallel to Shore Direction (km)
	5	0.85	3.91	1.48
160	25	4.70	6.41	6.34
	45	5.57	4.91	6.10
	5	0.46	0.60	0.54
180	25	1.06	1.07	1.42
	45	0.70	0.83	0.89
	5	0.28	0.33	0.33
190	25	0.35	0.36	0.44
	45	0.10	0.10	0.51

The 160 dB re 1 μPa footprints for one day of nearshore surveying in shallow, mid-depth, and deep water are shown in Figure 8; the corresponding areas of the footprints are listed in Table 3.



(a) (b) (c)

Figure 8: Daily footprints for (a) shallow, (b) mid-depth, and (c) deep water nearshore surveys. The ensonified areas are shown in gray and survey lines are shown in black.

Table 3: Areas ensonified to 160 dB re 1 μPa for nearshore surveys in 24 hours.

Nearshore Survey Depth Classification	Depth Range (m)	Area Ensonified to 160 dB re 1 μPa (km^2)
Shallow	5-21	346
Mid-depth	21-38	458
Deep	38-54	455

4.3. Channel Survey Results

The distances to the 160, 180, and 190 dB re 1 μPa sound level thresholds for the channel surveys are shown below in Table 4. Distances correspond to the broadside and endfire directions.

Table 4: Distances to sound level thresholds for the channel surveys.

Sound Level Threshold (dB re 1 μPa)	Water Depth at Source Location (m)	Distance in the Broadside Direction (km)	Distance in the Endfire Direction (km)
160	80	4.24	4.89
180	80	0.91	0.98
190	80	0.15	0.18

The 160 dB re 1 μPa footprint for 24 hours of seismic survey in the inlet channel is shown in Figure 9; the corresponding area of the footprint is 389 km^2.

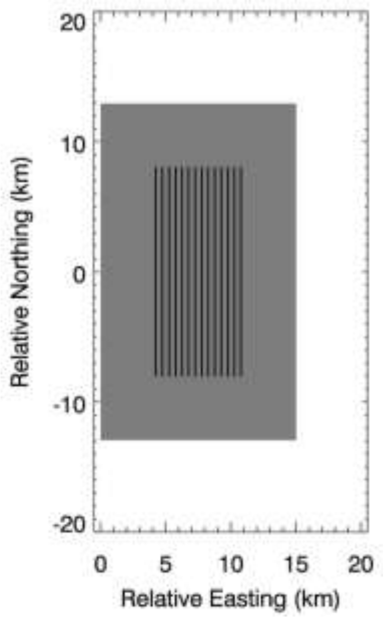


Figure 9: Daily footprint for channel surveys. The ensonified area is shown in gray and the survey lines are shown in black. Its area is 389 km^2.

5. Summary and Conclusion

This report presents results from a noise modeling study of Apache's planned seismic survey operations in Cook Inlet. The study characterized the acoustic environment in the Cook Inlet area by defining a generic nearshore sloped environment and a flat (constant depth) channel environment. Underwater noise was modeled from a 2400 in^3 airgun array and the distances that sound levels reached thresholds 160, 180, and 190 dB re 1 µPa (90% rms SPL) were computed. The areas ensonified above 160 dB re 1 µPa were calculated for 24 hour surveying periods in shallow, mid-depth, and deep water for the nearshore environment, and for 24 hours of surveying in the channel environment.

The signature of the 2400 in^3 airgun array was modeled using an airgun array source model (AASM) and was input to a range-dependent acoustic model in full waveform mode (MONM). Bathymetry has substantial influence on the distances that sound travels in the environments considered. Seismic sounds are predicted to propagate most strongly in the 21-55 m depth range, with greater attenuation (reduction of sound levels) for smaller and greater depths.

The maximum predicted distances for 90% rms SPL values to reach thresholds of 160, 180 and 190 dB re 1 µPa over all depths and azimuths modeled were 6.41 km, 1.42 km, 0.51 km, respectively. The areas ensonified above 160 dB re 1 µPa during 24 hours of surveying for the different environments considered is summarized in Table 5. These values can be used to estimate the number of takes expected over the course of a multi-day survey by simply multiplying by the corresponding animal spatial densities.

Table 5: Summary of ensonified areas to 160 dB re 1 µPa for one day of surveying.

Survey Classification	Depth Range (m)	Area Ensonified to 160 dB re 1 µPa (km^2)
Nearshore - Shallow	5-21	346
Nearshore - Mid-depth	21-38	458
Nearshore - Deep	38-54	455
Channel	80	389

Literature Cited

Collins, M.D. 1993. The split-step Padé solution for the parabolic equation method. *J. Acoust. Soc. Am.* 93:1736–1742.

Hamilton, E.L. 1980. Geoacoustic modeling of the sea floor. *J. Acoust. Soc. Am.* 68:1313–1340.

Hannay, D. E., & Racca, R. G. 2005. Acoustic Model Validation. Technical Report for: Sakhalin Energy Investment Corporation by JASCO Research Ltd.

Hashash, Youssef, 2008. A 2008 Update of Port of Anchorage Seismic Site Response Study. Report for Terracon Consultants, Inc.

JASCO Research Limited. 2007. Underwater Sound Level Measurements of Airgun Sources from ConocoPhillips' 2007 Beluga 3D Seismic Shoot, Cook Inlet, Alaska. 72 hour Report. ConocoPhillips Alaska Inc. 8p.

Teague, W.J., M.J. Carron, and P.J. Hogan. 1990. A comparison between the Generalized Digital Environmental Model and Levitus climatologies. *J. Geophys. Res.* 95(C5):7167–7183.

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 (4) 2007.

APPENDIX D

JASCO REVISED AREAS TO 160dB re 1 µPA – 2400 in^3 ARRAY

Apache Cook Inlet Seismic Survey Sound Levels

Revised Areas to 160 dB re 1 µPa – 2400 in^3 array

Submitted to:
Marta Czarnezki
Apache Alaska Corporation

Authors:
Melanie Austin

3 October 2013

P001230
Version 1.0 DRAFT

JASCO Applied Sciences
2200 W 29th Ave, Unit 1.
Anchorage, AK 99517 USA
Phone: +1-907-538-7205
Fax: +1-250-483-3300
www.jasco.com

Suggested citation:

Austin, M. 2013. *Apache Cook Inlet Seismic Survey Sound Levels: Revised Areas to 160 dB re 1 μPa – 2400 in3 array*. Version 1.0 DRAFT. Technical report by JASCO Applied Sciences for Apache Alaska Corporation.

Contents

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1. Introduction

This brief report contains revised estimates for areas of sound exposure associated with Apache Alaska Corporation's planned seismic surveys in Cook Inlet, Alaska. Sound from seismic survey airgun arrays has the potential to harass nearby marine mammals. The National Marine Fisheries Service (NMFS) presently considers impulsive airgun sound levels above 160 dB re 1 μPa (rms) as capable to cause harassment to marine mammals. Exposures above this threshold are considered level-B takes by NMFS (in contrast to level-A takes which refer to injury). Level-B takes generally need to be permitted under Incidental Harassment Authorizations (IHA).

JASCO Applied Sciences performed an acoustic modeling study in 2011 to estimate underwater sound levels produced by the airgun arrays of Apache's planned seismic surveys. A goal of the acoustic modeling work was to estimate areas of sound exposure using modeled distances to the 160 dB re 1 μPa (rms) threshold. These areas were used to calculate the marine mammal take numbers requested in Apache's IHA application.

A seismic survey took place in 2012, under the approved IHA, during which in-water sound level measurements were collected. The maximum measured distances from the airgun array to 160 dB re 1 μPa (rms) exceeded the model estimates by ratios of 1.21 to 1.50. This report describes the comparison of model predictions with measurements, and suggests adjustment factors based on the ratios of these threshold distances. Updates to the estimated areas over which the 160 dB re 1 μPa (rms) threshold will be exceeded were calculated by applying these adjustment factors to the original model results for all bathymetric scenarios considered. These results are suitable for use at calculating updated estimates of take for further surveys using the same type of survey equipment in these areas.

Full details of the underlying acoustic model and the techniques for calculating the areas of sound exposure can be found in the original modeling report from 2011 (Warner et al, 2011). Details and results from the 2012 measurement study can be found in the 5-day Sound Source Verification report from 2012 (Austin and Warner, 2012).

2. Methods

2.1. Calculation of areas of sound exposure

This section provides a brief review of the process used to calculate the areas of sound exposure, as detailed in the 2011 model report (Warner et al, 2011). This same process was used to obtain the areas in this current report, with the only difference being in the application of revised distances of the 160 dB re 1 μPa threshold from the survey line.

The original model study provided the area ensonified at levels above 160 dB re 1 μPa over 24 hours of seismic surveying. This area is dependent on the seismic survey line geometry because there is often overlap of the ensonified areas of multiple survey lines. Based on a general survey description, we computed the total area of sound exposure over 24 hours of seismic surveying assuming 12 to 14, 16.1 km survey lines would be acquired each day.

JASCO's sound propagation model MONM was used to model sounds from the array for several survey environments characteristic of Cook Inlet. The modeling study considered three nearshore environments with sloped seafloor and either shallow (5 m), mid-depth (25 m), or deep (45 m) water depth at the airgun position. A deep channel environment was modeled with a constant water depth of 80 m.

For the nearshore survey lines, the source was modeled at three positions on the slope with water depths of 5, 25, and 45 m. At each source position, three transects were modeled corresponding to the onshore, offshore, and parallel-to-shore directions. Since the airgun array will be towed parallel to shore, these directions correspond with the onshore-broadside, offshore-broadside, and endfire directions relative to the array. For the deep channel survey lines, the source was modeled in 80 m deep water in the broadside and endfire directions. The distances to 160 dB re 1 μPa were calculated in each direction using MONM, by considering the maximum level over all possible receiver depths.

The acoustic footprint for each survey line was calculated by defining encompassing rectangles formed by the distance of the 160 dB re 1 μPa threshold from the survey line, accounting for the differences in these distances for the different directions (Figure 1). The total area ensonified over the period of 24 hours was calculated from the union of 14 single survey line rectangles. Figure 2 illustrates the process for the union of just two survey line rectangles; this process was extended to all 14 lines of one day's anticipated survey production.

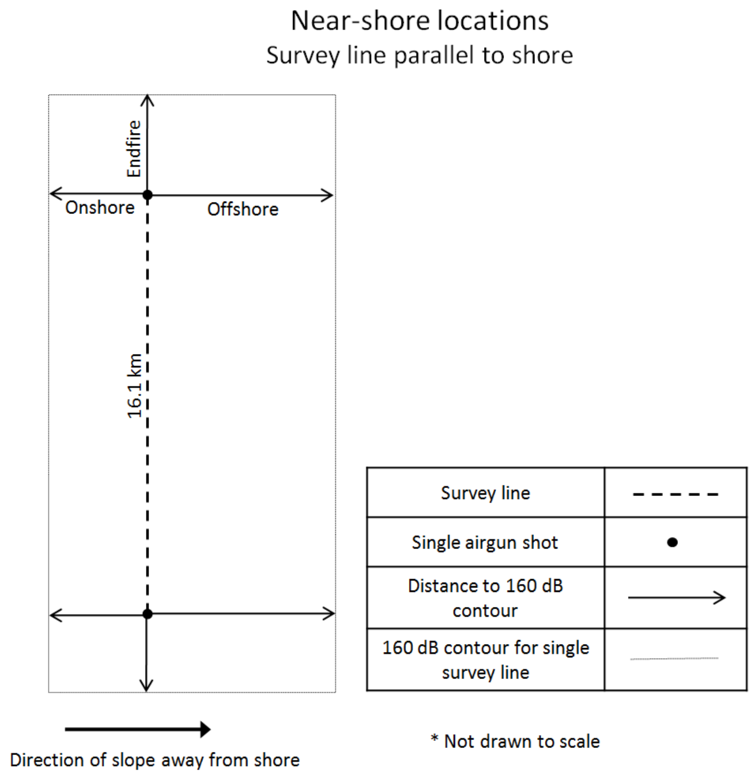


Figure 1: Diagram showing the creation of the 160 dB rectangular contour for a single survey line. In practice the corners are rounded but this has only a small influence on total area reduction.

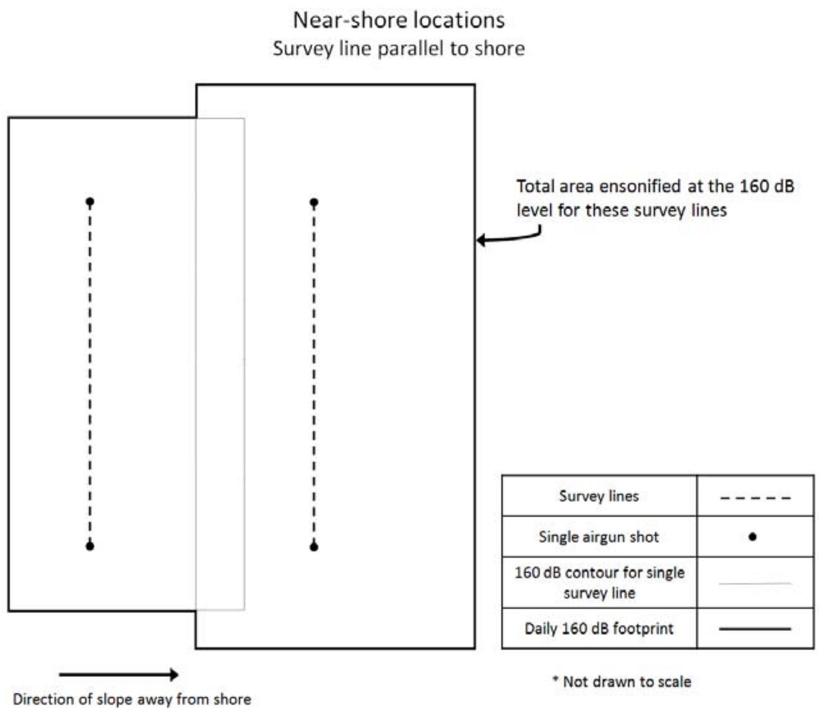


Figure 2: Diagram showing the union of two 160 dB rectangles (light grey lines) from two survey lines to get the combined 160 dB footprint (bold black line). The more offshore survey line (right) is in deeper water which supports better sound propagation. It consequently has a larger individual footprint size, hence its larger rectangle.

2.2. Threshold distance adjustments

Revised distances from the airgun array to 160 dB re 1 μPa were calculated by applying an offset to the 2011 model estimates. This offset was determined from the ratio of measured to modeled distances. This comparative analysis only considered measurements collected in conditions that were accurately reflected by one of the modeled environments (nearshore and offshore).

Measurements were collected for a nearshore survey line with water depths between 25 and 35 m (referred to as "Track 1" in the 2012 measurement report). These data were compared against the modeled distances for the nearshore, mid-depth survey classification. The data-to-model ratio was determined for the 160 dB re 1 μPa threshold distance in both the offshore-broadside and endfire directions (Table 1). This ratio formed the factor by which modeled distances to 160 dB re 1 μPa were increased. Measurements were not available for the onshore-broadside direction, but the offset was assumed to be the same as that for the offshore-broadside aspect. These broadside and endfire offsets were also applied to the modeled distances for the two other (shallow and deep water) nearshore environments.

Measurements were collected for a deep channel survey line (referred to as 'Track 2' in the 2012 measurement report) with water depths of 65 m and less. The bathymetry along the survey track was not constant and the source vessel was in relatively shallow water (<40 m) at ranges from the recorder beyond 5 km. These water depths differed significantly from the 80 m depth that was modeled. In addition, the distances in the measurement report were derived from an extrapolation using a data-fit that neglected long-range absorption effects and likely over-estimated the true range to 160 dB re 1 μPa (Austin and Warner, 2012). For these reasons, this was not considered to be a valid comparison and a data-to-model offset was not computed from these data. The offsets from the near-shore environment were, thus, also applied to the deep channel model estimates.

Table 1. Range to 160 dB re 1 μPa (rms) for the broadside and endfire aspects of a 2400 in^3 airgun array operating along a nearshore survey line.

	Broadside (km)	*Endfire* (km)
2011 Model Estimate (Mid-depth, offshore-broadside)	6.41	6.34
2012 Measurement (Track 1, offshore-broadside)	7.77	9.50
Ratio Data:Model	121%	150%

3. Results

The distances to the 160 dB re 1 μPa (rms) threshold from the 2011 model results were each adjusted using the data:model ratios defined above (Table 2). These adjusted threshold radii were used to re-compute the areas of ensonification. The revised areas are listed in Table 3.

Table 2 Ranges to 160 dB re 1 μPa (rms) for three different aspects of a 2400 in^3 airgun array.

	Water Depth at Source Location (m)	Distance in the Onshore Direction (km)	Distance in the Offshore Direction (km)	Distance in the Parallel to Shore Direction (km)
Original Model Estimates from 2011				
	5	0.85	3.91	1.48
	25	4.70	6.41	6.34
	45	5.57	4.91	6.10
	80	4.24	4.24	4.89
Adjusted Model Estimates Based on Offset from 2012 Measurements				
	5	1.03	4.73	2.22
	25	5.69	7.77	9.50
	45	6.75	5.95	9.15
	80	5.14	5.14	7.33

Table 3 Ensonified areas to 160 dB re 1 μPa for one day of surveying.

Survey Classification	Depth Range (m)	Area Ensonified to 160 dB re 1 μPa (km^2)	
		2011 Estimate	Revised Estimate
Nearshore - Shallow	5-21	346	462
Nearshore - Mid-depth	21-38	458	629
Nearshore - Deep	38-54	455	623
Channel	80	389	517

4. Conclusion

Measurements collected in 2012 yielded distances to 160 dB re 1 μPa (rms) that exceeded model estimates from 2011 by a ratio of 121% in the offshore-broadside direction and 150% in the endfire direction. The modeled distances have been increased by the offset between the measured and modeled values. Areas of ensonification to 160 dB re 1 μPa (rms) have also been revised and are summarized below.

Survey Classification	Depth Range (m)	Area Ensonified to 160 dB re 1 μPa (km^2)
Nearshore - Shallow	5-21	462
Nearshore - Mid-depth	21-38	629
Nearshore - Deep	38-54	623
Channel	80	517

Literature Cited

Austin, M.A., and G. Warner. 2012. Sound Source Acoustic Measurements: Version 2.0. Technical report for Fairweather LLC and Apache Corporation by JASCO Applied Sciences.

Warner, G., J. Wladichuk and D.E. Hannay. 2011. Hydroacoustic Modeling of Airgun Noise for Apache's Cook Inlet Seismic Program: Daily Acoustic Footprint Calculations Version 1.0. Technical report for Fairweather LLC by JASCO Applied Sciences.

APPENDIX E

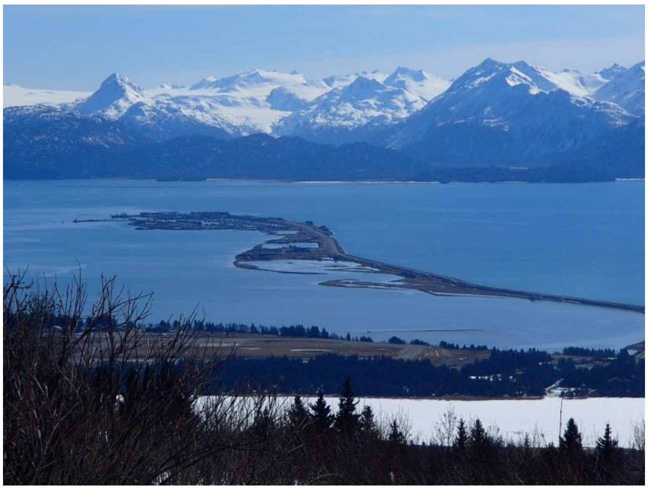
Seiche Sound Source Verification of Airguns 2014

Seiche Measurements Ltd
Bradworthy Industrial Estate
Langdon Road, Bradworthy
Holsworthy, Devon EX22 7SF
United Kingdom
Tel: +44 (0) 1409 404050
Fax: +44 (0) 1409 240276
Email: info@seiche.eu.com
Web: www.seiche.eu.com

Sound Source Verification
Final Report

Cook Inlet Seismic Survey,

Apache, Alaska.



Authors;

Brian Heath
Guillermo Jiménez
Kaya Marks

9th May 2014

Doc 1404A – Revision 1.0

Contents

Figures

Tables

1 Introduction

This report presents the findings of the Sound Source Verification study carried out by Seiche Measurements on behalf of the Apache Corporation, Alaska. It will outline the sound propagation from these sources in seawater and identify the extents to which 160 dB, 180 dB and 190 dB re $1\mu Pa_{rms}$ limits are in relation to that source both modelled and measured.

The sound from the source can propagate great distances however, the amplitude will vary as the distance increases so the SPL's defined above can be calculated and described as a distance from the source. Many factors can affect this propagation including, but not limited to, water temperature, salinity and bathymetry.

The report will describe the computer model and acquisition methods used and present the results for the different sources at the prescribed sound pressure levels (SPL_{rms}). There are many thousands of randomized data points acquired during this study in order to give as accurate a prediction as possible. The modelling is used as a guide to the expected limits.

2 Acoustic Sources

Two different airgun arrays are to be used for this acoustic study and are detailed in sections 2.1 & 2.2, one having a volume of 440 in^3 and the other 1760 in^3.There is a single location for 440in^3 plus a shallow and deep location for the 1760 in^3.An example of the 1760 in^3 array is shown in Figure 1.

Figure 1 - Acoustic Array Prior to Deployment.

2.1 440 in^3 Seismic Airgun

This array comprises of a SeaScan USW 440 2M, having a total volume of 440.0 in^3 and an expected SPL of 9.00 bar m. This will be a small array of 4 cluster guns (Figure 2) each producing 2000 psi.

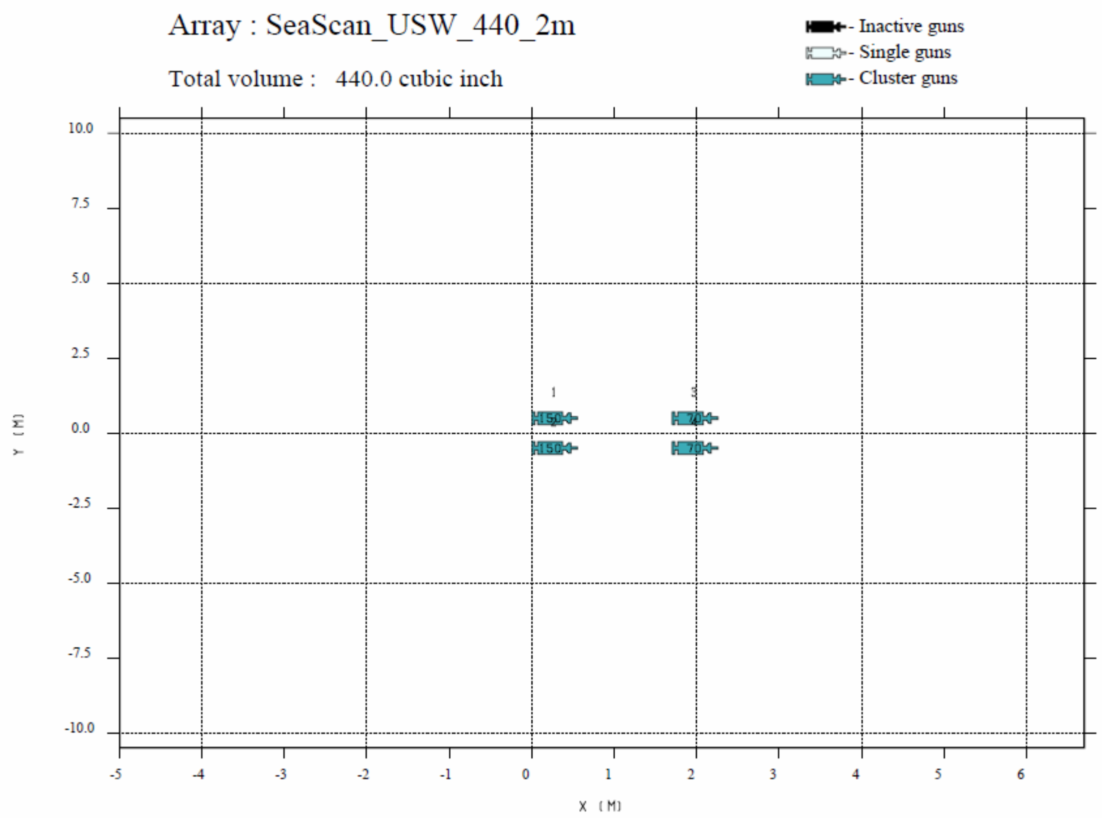


Figure 2 - SeaScan USW 440 2M

This source array will operate at a constant 2 m depth and the modelled far field signature is shown in Figure 3. The source directivity is primarily omni-directional and this has been assumed for the purpose of the modelling.

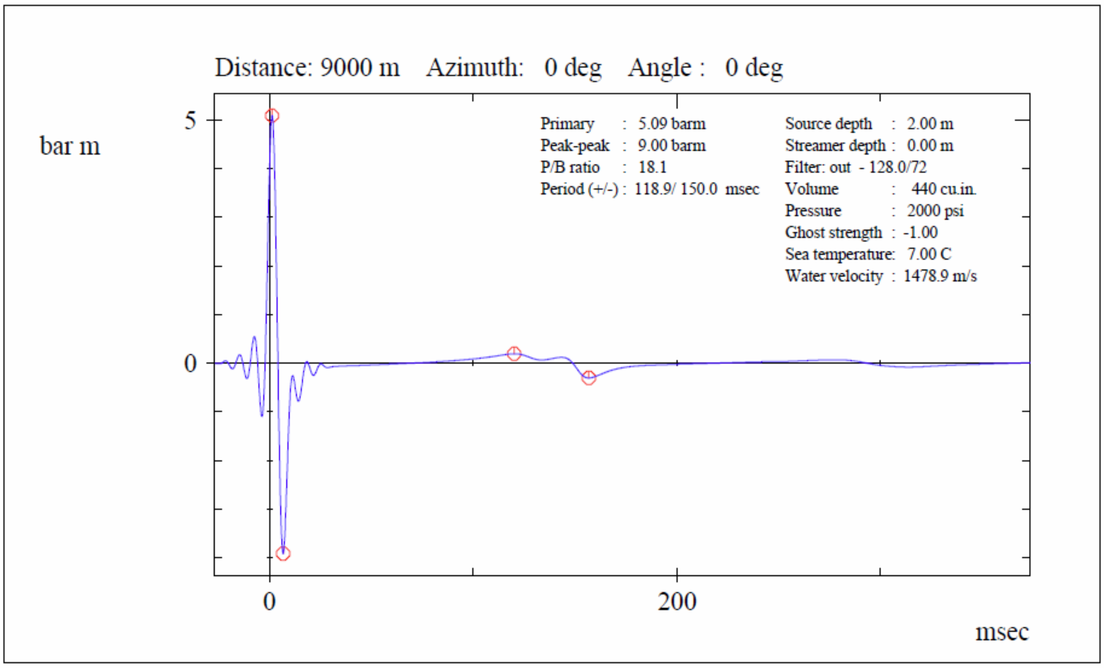


Figure 3 - SeaScan USW 440 @ 2M Far Field signature

2.1.1 440 in^3 Seismic Airgun - SPL Calculation

In order to model the propagation it is necessary to convert the predicted SPL from bar m to dB re 1 µPa. The following equations are applied to generate the equivalent SPL.

$$SPL_{Pascals} = SPL_{bar} \times 100000$$

Equation 1

$$dB\ re\ 1\ \mu Pa = 20Log\left(\frac{SPL_{Pascals}}{0.000001}\right)$$

Equation 2

$$\therefore 9.00\ barm = 239.08\ dB\ re\ 1\ \mu Pa$$

2.2 1760 in^3 Seismic Airgun

Array B comprises of a SeaScan 2x880 3M, having a total volume of 1760 in^3 and an expected SPL of 50.70 bar m. This will be a larger array of 16 guns arranged in 6 clusters (Figure 4) each producing 2000 psi.

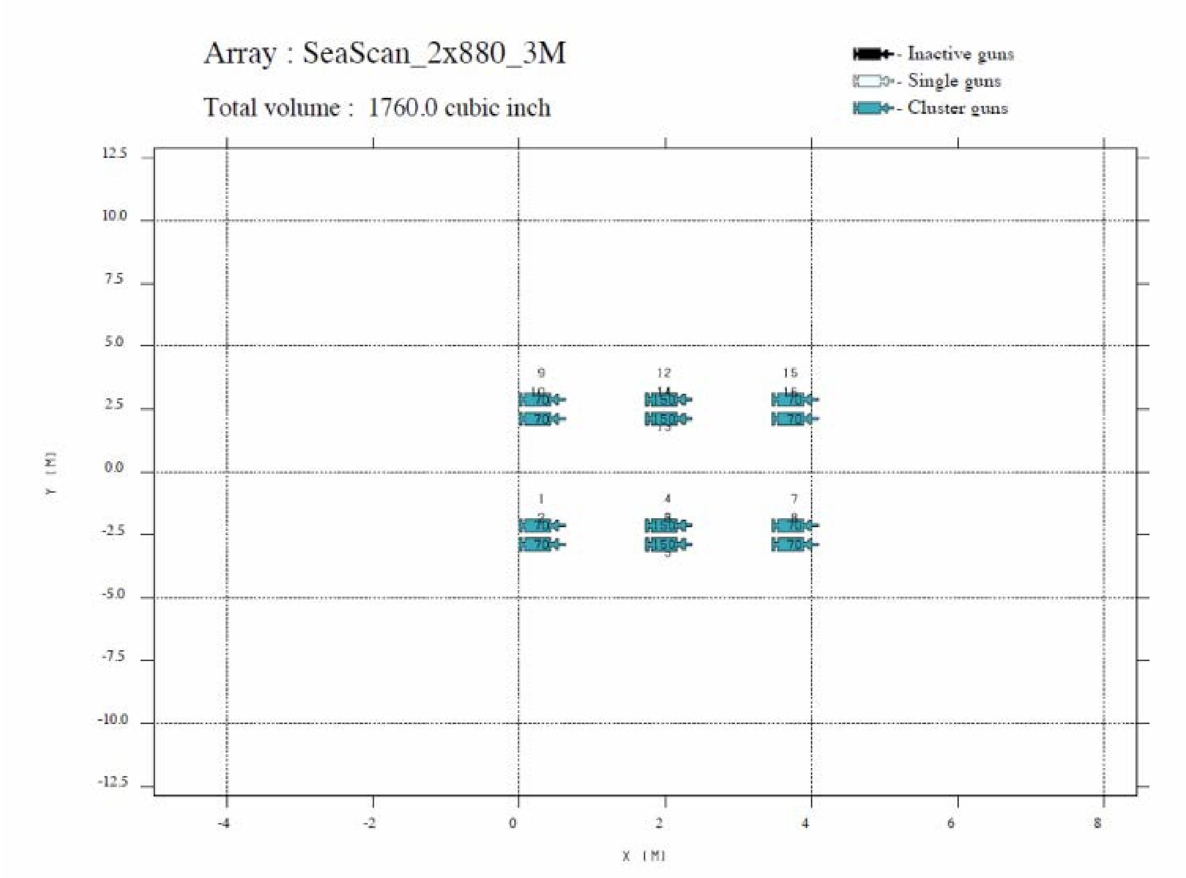


Figure 4 - SeaScan 2 x 880

This array will operate at a constant 3 m depth and the modelled far field signature is shown in Figure 5. The source directivity is again, primarily omni-directional and this has been assumed for the purpose of the modelling.

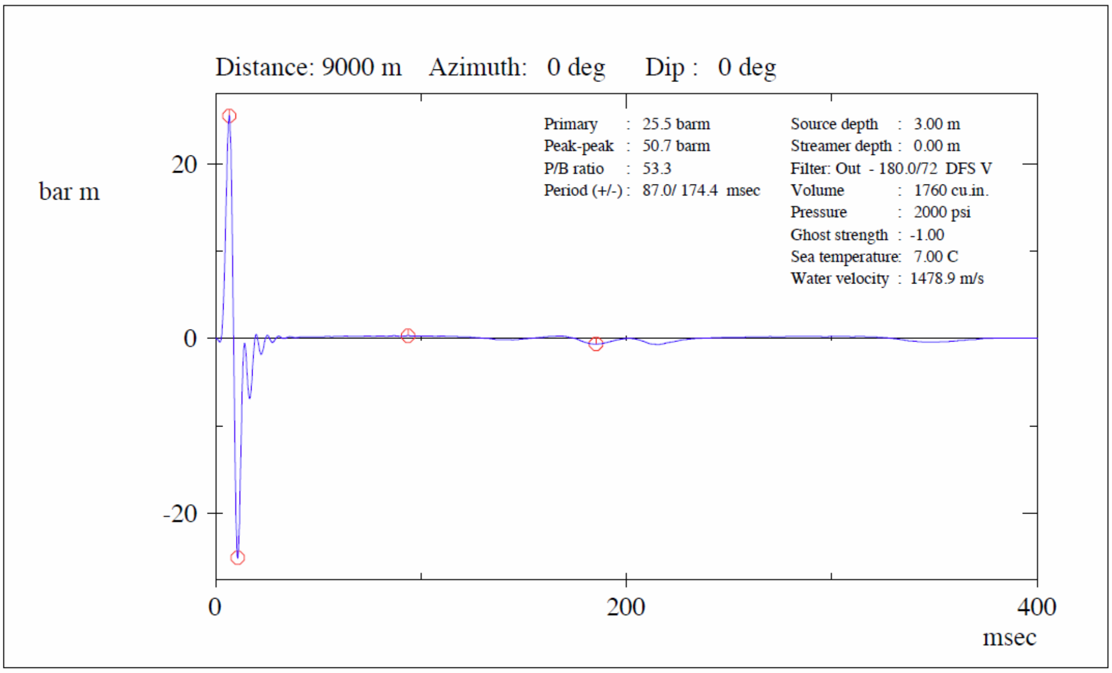


Figure 5 - SeaScan 2 x 880 @ 3M Far Field Signature

2.2.1 1760 in^3 Seismic Airgun - SPL Calculation

In order to model the propagation it is necessary to convert the predicted SPL from bar m to dB re 1 µPa. Applying equations from section 2.2.1 the SPL becomes;

$$\therefore 50.7\ barm = 254.10\ dB\ re\ 1\ \mu Pa$$

3 Acoustic Metrics

This report will focus on arguably the most important metrics used in underwater sound; SPL_{peak}, SPL_{rms} and SEL.

All have their uses in marine acoustics, particularly when the effect of noise is to be related to marine mammals and the like.

The peak SPL can typically be portrayed in two different forms; Peak-to-Peak or Zero-to-Peak.

Theobalda et al. (2009), describe the benefits of this metric being used to describe the instantaneous sound pressure at a given location and can, if loud enough, be linked to Permanent Threshold Shift (PTS) in marine mammals.

However, due to the amplitude required to induce PTS, expressed by NOAA (2013) [Ref: 8] as 230 dB re 1 μPa Peak for Low frequency Cetaceans, it is highly unlikely that this amplitude could occur in this scenario.

Therefore, it may be appropriate to specify sound levels using Root Mean Square (rms) values because there is a direct relationship between the rms value and energy. By using this method, both the amplitude of the seismic shot and the duration of that shot are defined in a signal unit, both of which are of in great importance when estimating physical and neurological effects to marine mammals.

The duration of the pulse, T, has been calculated using the 90% rule formed by Greene (1997) [Ref: 4] and also cited in Needham (2010) [Ref: 6]. The suggestion is based on using a time window that removes the first and last 5% from the seismic pulse.

The rms is the mean square sound pressure level typically integrated over a window, T, encompassing the energy in the pulse.

$$rms = 20Log\left(\sqrt{\frac{1}{T}\int_0^T \frac{P^2(t)}{P_0}dt}\right)$$

Where:

P_0= 1 µPa

T= duration, seconds

P(t)=sound pressure

4 Seismic Survey

The survey has been undertaken in the Cook Inlet, Alaska. The location for the survey is in close proximity of the Kenai Peninsula and immediately adjacent to Kenai. This is shown in Figure 6.

Figure 6 - Survey Location

4.1 Methodology

Seiche Measurements Ltd novel method for the characterisation of seismic sources alleviates many of the problems associated with a typical static hydrophone deployment.

Robinson et all (2014) [Ref: 5] suggests that static deployments often suffer from tidal flow and debris noise during the survey. Due to the unique tidal flow conditions presented in the Cook Inlet, this could have proved very difficult to utilise effectively.

The main disadvantage with a static system is that by definition they are static. This means that the bathymetry profile and other important sound propagation factors will only be gathered at the location of the static recorders. The other disadvantage of a static system is the need to secure the recorder to the seabed-which would consequently need permission from the regulatory office in that constituency and have potential environmental effects.

The drift buoy method however, provides a dynamic method of capturing the sound at many locations, providing a large and well defined data set that illustrates the effect of a seismic source much more accurately than a limited number of static points.

An added benefit of the drift buoy solution is the scalability of the deployment-more buoys would yield better fidelity when interpolating between measurement locations.

During the survey, six data recording buoys have been deployed and allowed to drift in the tidal flow past the airgun sound source. The source was maintained in one position throughout each test run and the buoys were positioned at various intervals, covering a 8 km radius from the 440 in^3 source and 10 km from the 1760 in^3 source, across the survey area in order to maximise the coverage and to represent a wide variety of distances from the source airgun.

4.1.1 Study One - 440 in^3 Airgun in Shallow Water Location

The airgun source was positioned at 60.460254, -151.372638 and maintained this position for the tidal buoy run. The repetition rate was 10 seconds. The buoys were allowed to drift, in the tide, for over 3 hours collecting data from each sound shot. Over 8000 data points were recorded on this run. The buoy tracks can be seen in Figure 7 and the source is located at the centre of the 8 km circular marker zone.

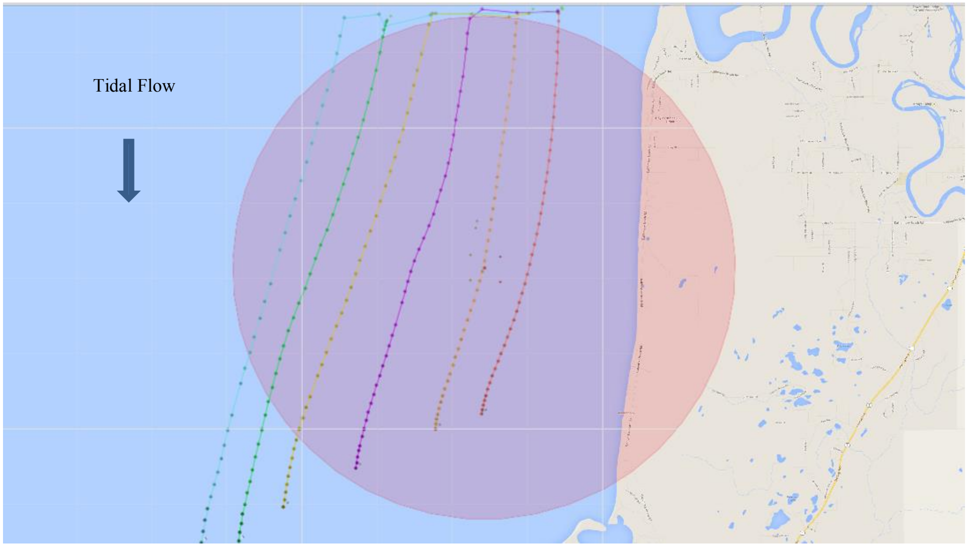


Figure 7 - 440 in^3, Test Buoy Tracks 3rd April 2014

4.1.2 Study Two - 1760 in^3 in Shallow Water Location

The same location has been used for the source, 60.460254, -151.372638 and again was maintained throughout the buoy run. The repetition rate for this source was set at 30 seconds. The buoys were allowed to drift, in the tide, for over 3 hours collecting data from each sound shot. Over 2000 data points were recorded on this run. The buoy tracks can be seen in Figure 8 with the source in the centre of the 10 km marker circle.

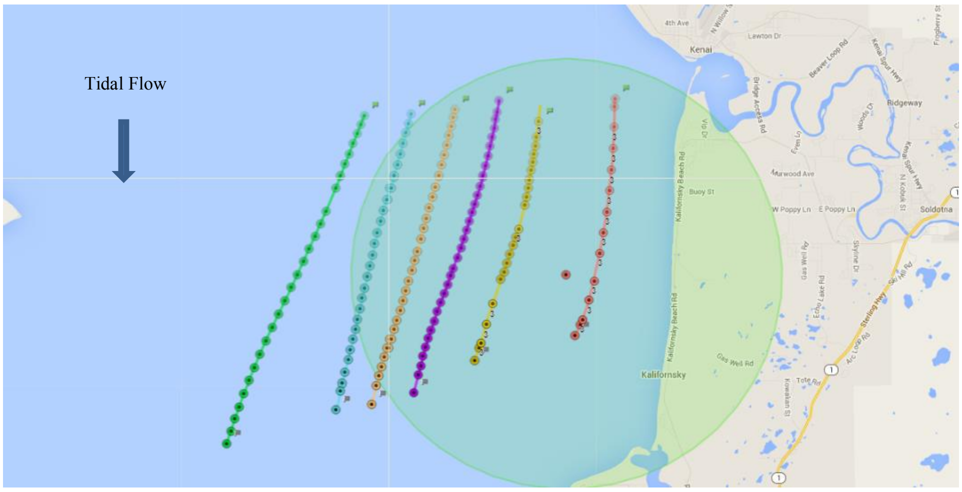


Figure 8 - 1760 in^3, Test Buoy Tracks 5th April 2014

4.1.3 Study Three - 1760 in^3 in Deep Water Location

The location of the source for the deep water study was 60.507910, -151.574560 and was maintained throughout the buoy run. The repetition rate for this source was set at 30 seconds. The buoys were allowed to drift, in the tide, for over 5½ hours collecting data from each sound shot. Over 3000 data points were recorded on this run. The buoy tracks can be seen in Figure 9 with the source in the centre of the 10 km marker circle. One of the buoys drifted quite wide and was physically repositioned within the zone. Data from this buoy during this process has been disregarded.

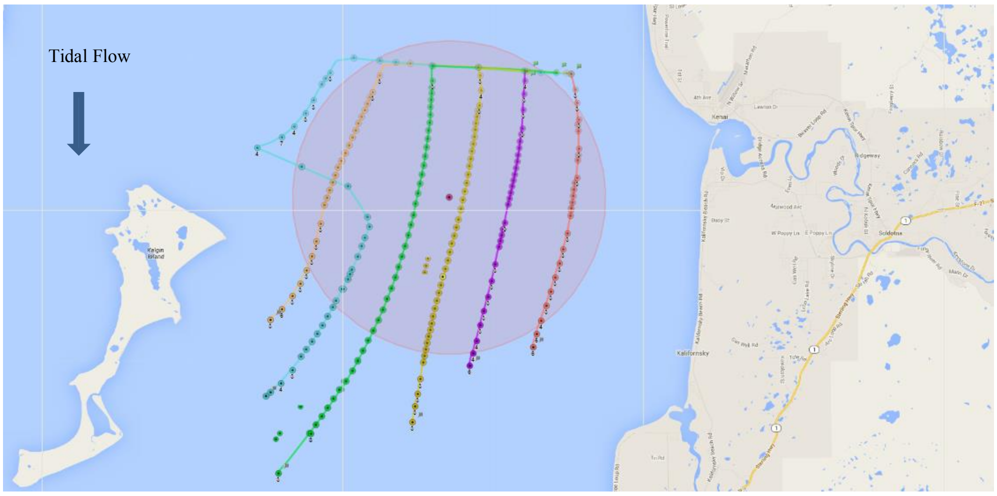


Figure 9 - 1760 in^3, Test Buoy Tracks 6th April 2014

4.2 Equipment and Calibration

Each drift buoy has been designed to house an autonomous data recording system, hydrophones, GPS location system, satellite location system and batteries. An example of the buoy can be seen in Figure 10. Each buoy is able to record 2 channels of high resolution acoustic data from two separate hydrophones. They are fitted with two Seiche Measurements propriety hydrophones and have individual nominal sensitivities of -200 dB re 1 V/µPa and -188 dB re 1 V/µPa respectively and have a frequency response range of 10 Hz – 100 kHz. The buoys data capture system has been individually calibrated prior to deployment and the actual sensitivities have been applied to the recorded digital data throughout. The acoustic data has been captured in 16 bit resolution at 96 kHz on this deployment.

Figure 10 - Drift Buoy

5 Data Analysis and Results

5.1 Data Processing & Analysis

Collected data has been verified and analysed used Seiche Measurements proprietary Sound Source Verification software. The data has been processed using the following method.

- Peak detection algorithm has been applied in order to detect the sound shot peaks from the time line.
- The Peak to Peak values identified are correlated with the GPS positional data to provide an accurate distance from the source.
- The signal values are converted to dB re 1 V and then converted to SPL_{rms} giving full consideration to the calibration for each individual system.

5.2 Results

Results have been plotted as SPL_{rms} dB values against the calculated distance from the source.

5.2.1 440 in^3 Seismic Array in Shallow Water.

The calculated results of all the valid acoustic data from the buoys has been plotted as SPL_{rms} levels against distance from the source and are shown in Figure 11. The data shows a wide ranging distance spread over approximately 8.5 km for valid data. Three percentiles have been calculated for the 160 dB threshold and are shown on the graph. These are also detailed in Table 1 along with the information regarding the 180 dB and 190 dB zones. Levels for 190 dB have been estimated from the trend as no sound levels have been recorded this high.

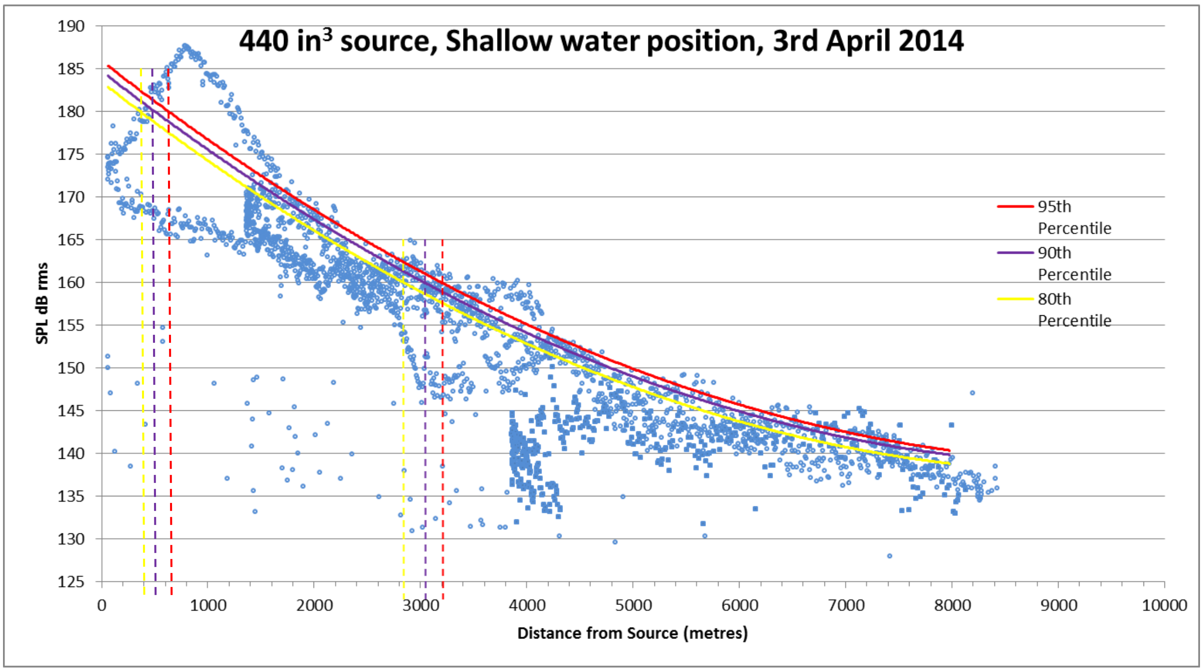


Figure 11 - 440 in^3 Source SPL dB_{rms} Levels vs Distance

	Range in Metres		
SPL_{rms} Level	80th Percentile	90th Percentile	95th Percentile
190 dB	<50	<100	<150
180 dB	400	500	650
160 dB	2850	3050	3210

Table 1 - 440 in^3 Source dB Radii

5.2.2 1760 in^3 Seismic Array in Shallow Water.

The calculated results of all the valid acoustic data from the buoys has been plotted as SPL_{rms} levels against distance from the source and are shown in Figure 12. The data shows a distance range spread over approximately 17.5 km for valid data. Three percentiles have been calculated for the 160 dB threshold and are shown on the graph. These are also detailed in Table 2 along with the information regarding the 180 dB and 190 dB zones which have been estimated from the trend as no sound levels of this intensity have been recorded.

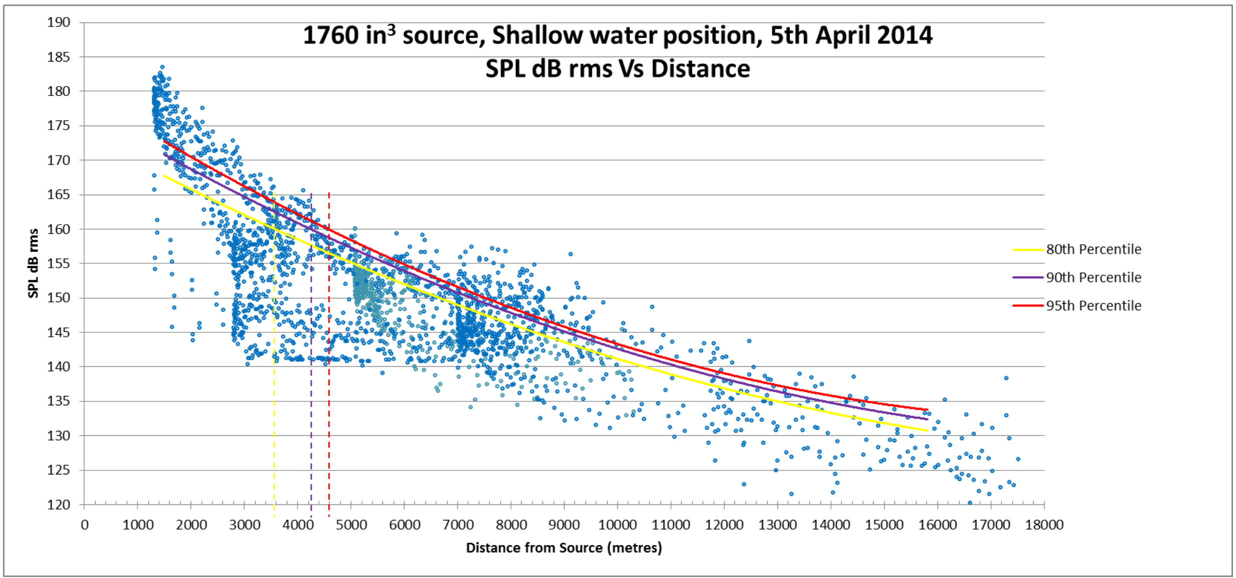


Figure 12 - 1760 in^3 Source SPL dB_{rms} Levels vs Distance

SPL_{rms} Level	Range in Metres		
	80th Percentile	90th Percentile	95th Percentile
190 dB	<700	<850	<1000
180 dB	1451	1514	1543
160 dB	3580	4270	4600

Table 2 - 1760 in^3 Source dB Radii (Shallow Water)

5.2.3 1760 in^3 Seismic Array in Deep Water

The calculated results of all the valid acoustic data from the buoys has been plotted as SPL_{rms} levels against distance from the source and are shown in Figure 13. The data shows a distance range spread over approximately 17.5 km for valid data. Three percentiles have been calculated for the 160 dB threshold and are shown on the graph. These are also detailed in Table 3 along with the information regarding the 180 dB and 190 dB zones.

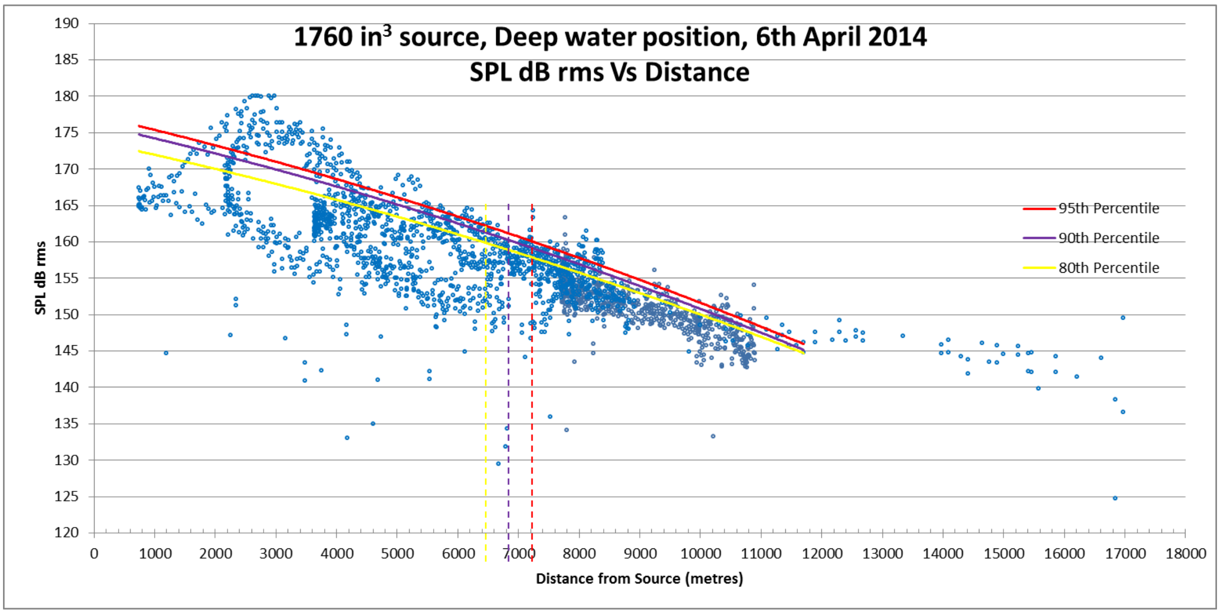


Figure 13 - 1760 in^3 Source SPL dB_{rms} Levels vs Distance (Deep Water)

	Range in Metres		
SPL_{rms} Level	**80th Percentile**	**90th Percentile**	**95th Percentile**
190 dB	<850	<1000	<1200
180 dB	2780	2832	2859
160 dB	6450	6830	7190

Table 3 - 1760 in^3 Source dB Radii (Deep Water)

6 Modelling

Modelling has been implemented using AcTUP (Acoustic Toolbox User interface and Post-processor, v.2.2l), a powerful software for sound propagation simulation in underwater environment. AcTUP core is based on consistent and thoroughly developed theories for prediction of sound behaviour in water, nevertheless as a model the results should be taken with caution. Accuracy of simulated models is always better when supported by measurements (empirical results) and a good definition of model parameters. In order to ensure model accuracy and comparison with survey results a dense set of official bathymetry data from NOAA and parameters of the environment from a previous survey in the Cook Inlet [Ref: 1] and position, depth and performance parameters from the sources and hydrophones deployed has been used.

The method chosen for the acoustic modelling is the parabolic equation, in particular RAMGeo model, which provides the best results for low frequencies both in shallow or deep water.

6.1 Bathymetry

High density bathymetry data from NOAA has been utilised to extract appropriate profiles relative to the test area and have been used in the acoustic propagation model. A set of 18 bathymetry profiles, at 20˚ steps, have been introduced into the data modelling software AcTUP to obtain the respective transmission loss profiles.

The Bathymetry along the Cook Inlet survey test area suggests it is fairly uniform, ranging in depth from 2m to 80m and as such a few data points are enough to define the bathymetry profile for each angle considered. For this model points at 250 m steps have been taken. A modelled topology of the Cook Inlet is shown in Figure 14.

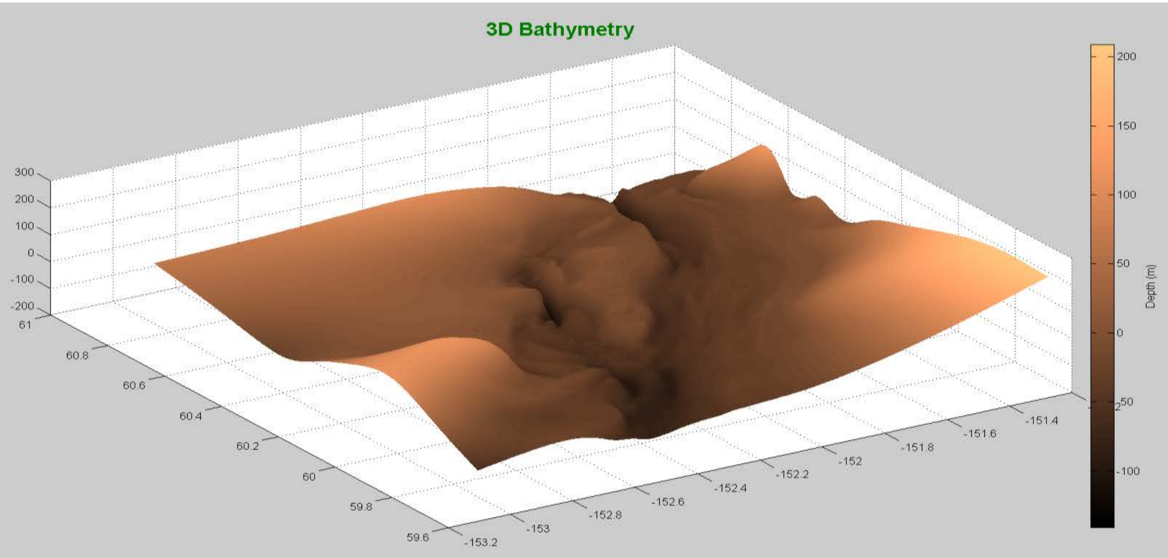


Figure 14 - Cook Inlet Topology

These bathymetry profiles have been extracted for two source positions, the same as used in the survey: one for shallow water, located at (60.460254, -151.372638); and another one for deep water, located at (60.507910, -151.574560).

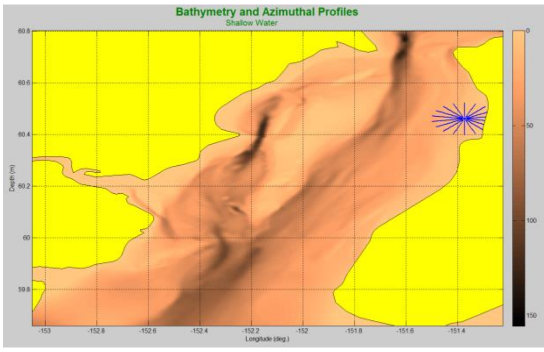


Figure 15 - Deep Water Bathymetry

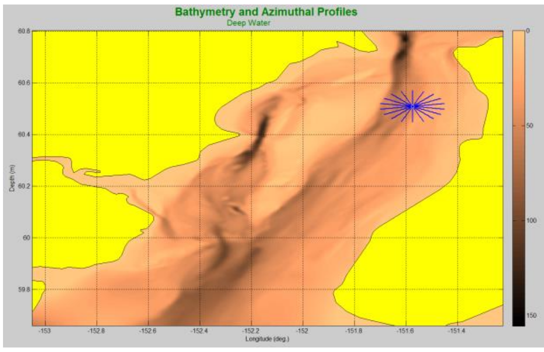


Figure 16 - Shallow Water Bathymetry

Both source positions, along with the profile segments, are represented in Figure 15 and Figure 16. The corresponding bathymetry profiles are drawn in Figure 17 and Figure 18, respectively.

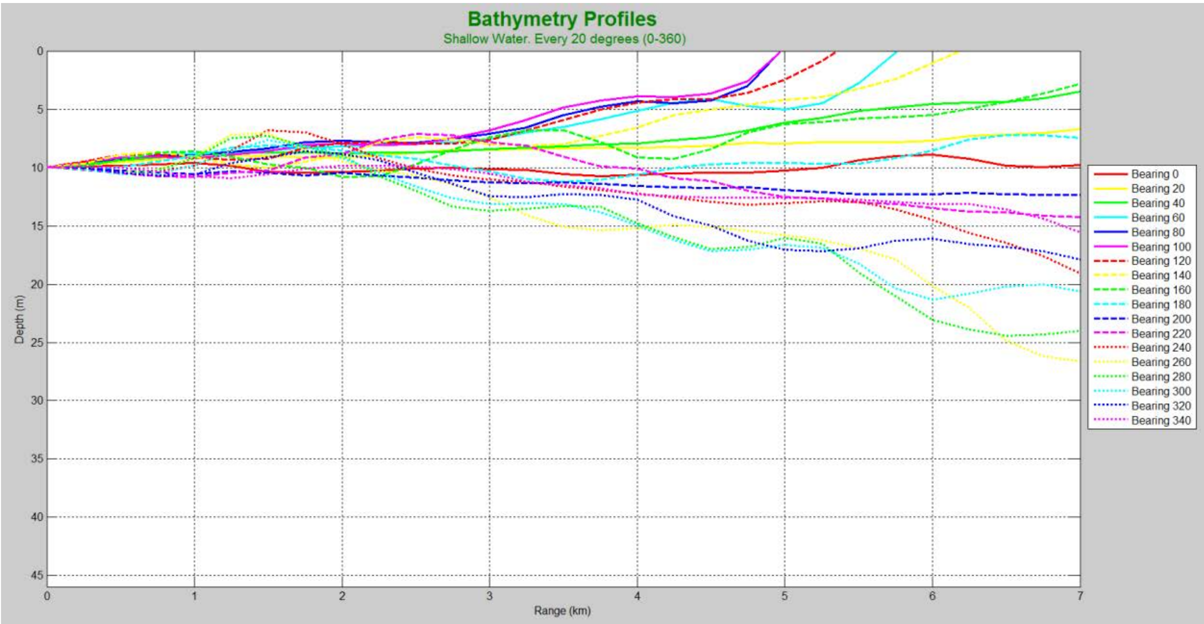


Figure 17 - Shallow Water Profiles

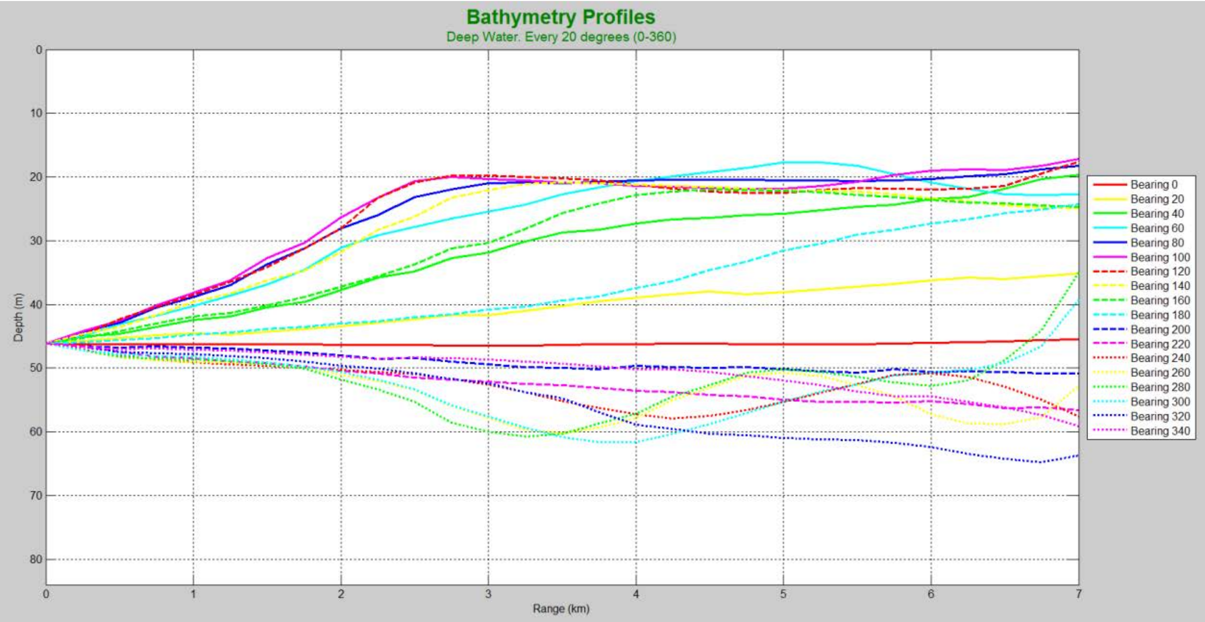


Figure 18 - Deep Water Profiles

6.2 Geology

The Cook Inlet comprises, in the main from two types of layers;

- Soil layer, a combination of sand, silt and clay
- Glacial layer, a combination of glacial fluvial sands, gravels and glacial till.

Applying methods originally described by Hamilton (1980) qualitative descriptions have been used to define the geo-acoustic properties in this area and have then been applied in the model.

6.3 Sound Velocity

The value applied for the model is 1436 ms^{-1}. Previous survey data has been used to establish a unique average sound velocity value for sea water in the area for this study [Ref: 1].

Table 4 shows the parameters used within the model.

	Compressional Sound Speed C_p (ms^{-1})	Shear Sound Speed C_p (ms^{-1})	Density (Kgm^{-3})	Compressional Attenuation ($dB\lambda^{-1}$)	Shear Attenuation ($dB\lambda^{-1}$)	Depth (m)
Water	1436	0	1024	0	0	Bathymetry
Soil Layer	1480	110	1580	0.17	2	108
Glacial Layer	1844	0	2180	0.5	0	Half-space

Table 4 - Geo-acoustic Profile

6.4 Modelling Assumptions

The modelling predictions provided are independent for both sources and use the following parameters throughout.

- Sound sources are primarily omni-directional
- Source frequency fundamental @ 90 Hz
- Source depth of 2 m (440 in^3) and 3 m (1760 in^3)
- Modelled Maximum range 7000m
- Low tide (distance from water surface to seabed defined by the bathymetry)

The frequency of the analysis has been matched to the highest energy content of the source frequency and has been modelled to a range of 7000 m in order to include the 160 dB, 180 dB and 190 dB mitigation zones.

6.5 Mitigation Zones Calculation

The transmission loss profiles obtained from AcTUP are combined with the source level (dB re 1 μPa_{rms}) of each source to get the receiver level profiles. The latter contains all the information about the propagation of sound and these are used to represent a SPL_{rms} map around the source, from which exclusion zones of 160, 180 and 190 dB can be extracted.

Peak to peak source levels have been extracted from sound pressure and impulsive signal information from the sources. In order to calculate rms it has been assumed that the value at a single frequency of 90 Hz contains all the energy of the pulse. This way the rms value can be estimated as:

$$\text{rms} = \text{SPLpp} - 20\log(2\sqrt{2})$$

This equates to a figure which is around 9 dB less than peak to peak value.

The SPL_{rms} map has been calculated by interpolation of the 18 transmission loss profiles. Data from transmission loss profiles has been used to calculate the mitigation zones. This way the exclusion lines are sharper but more realistic than if interpolation methods were applied.

The mitigation zones of 80th, 90th and 95th percentiles have been calculated for each exclusion level (160, 180 and 190 dB). A mitigation zone of a particular percentile is represented by a closed line around the source. The area inside this line is the region where exists a particular probability (determined by the associated percentile) to find that exclusion level. For example, the 90th percentile of the 160dB mitigation zone provides the limit at which there is a 90% probability of 160 dB exposure being contained inside. In practice, a single exclusion level value is not used; it is necessary to establish a small range around it to get a set of values to average and process using simple statistic techniques. Then, for each transmission loss profile a set of distance values corresponding to that set of sound level values is obtained. The set of exclusion level values is defined by exclusion level ±1.5 dB. If the probability distribution function of those distances is represented, a bell shape or Gaussian distribution will be observed. This way the distance of a particular percentile for each of the 18 directions considered and a particular exclusion level can be calculated as:

$$\bar{x} + z\sigma$$

Equation 3

Where x is the set of distances, $\bar{x}$ and σ are average and standard deviation and z the standard score or z-score for that percentile. The z-score values for the three percentiles considered (left tail probabilities) are the following:

$$80\% \rightarrow z = 0.842$$

$$90\% \rightarrow z = 1.282$$

$$95\% \rightarrow z = 1.645$$

7 Modelling Results

Two models have been computed in AcTUP in order to extract the transmission loss profiles: a shallow and a deep water model. They have been modelled to 7000 m extents and the 160 dB, 180 dB and 190 dB mitigation zones have been identified for both the lower pressure (LP) sound source (9 barm, 440 in^3) and the higher pressure (HP) one (50.7 barm, 1760 in^3) . The same three situations as in the Cook Inlet study have been modelled: HP source in deep water, HP source in shallow water and LP source in shallow water. Each case has been modelled for two different receiver depths: about 3 m (2.5 m for LP source and 3.5 m for HP source, taking into account the different depth for both sources) and 6 m. The SPL map (receiver levels) and the three mitigation zones can be seen in Figure 19 to Figure 24, for each source-depth context case and receiver depth. The frequency of the analysis has been matched to the highest energy content of the source frequency and has been modelled to a range of 7000 m in order to include the 160 dB, 180 dB and 190 dB mitigation zones. The modelled results for the 90th percentile are shown in Table 5.

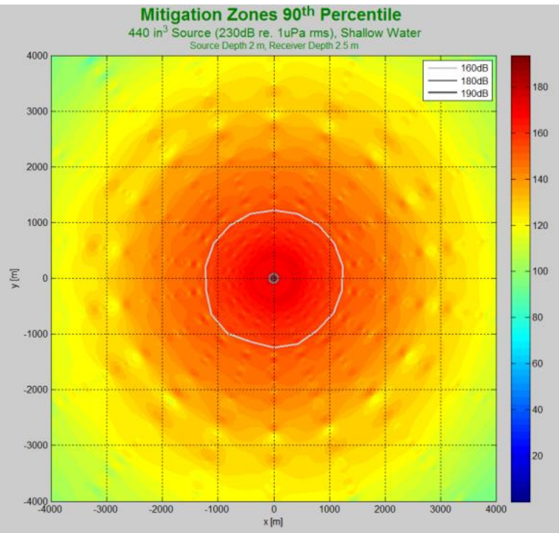


Figure 19 - Modelled Zone 440 in^3, Shallow Water, Depth 2.5m

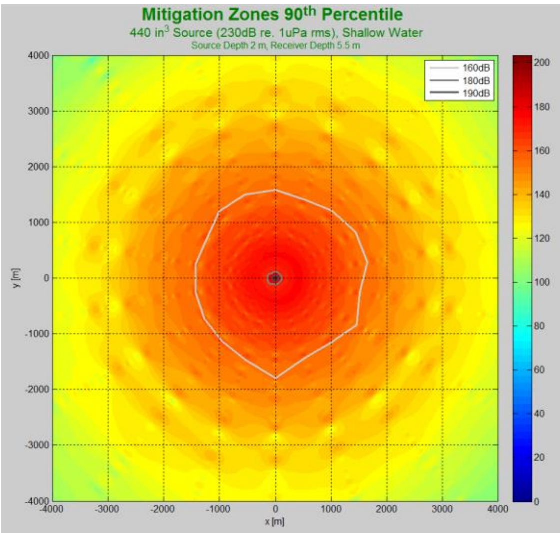


Figure 20 - Modelled Zone 440 in^3, Shallow Water, Depth 5.5m

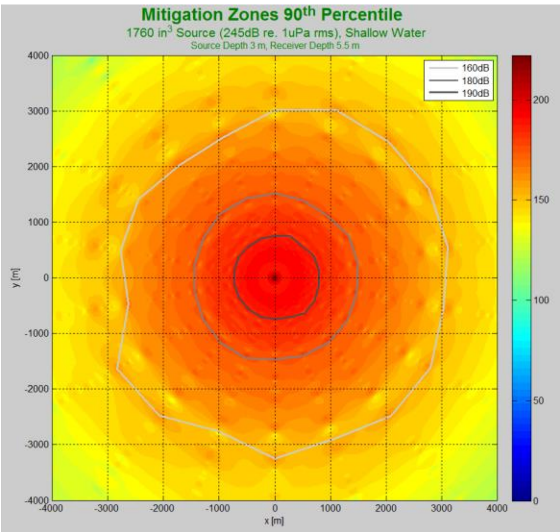


Figure 22 - Modelled Zone 1760 in^3, Shallow Water, Depth 5.5m

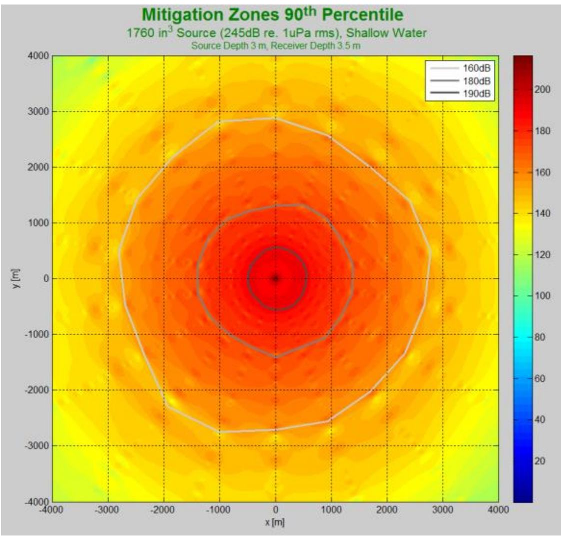


Figure 21 - Modelled Zone 1760 in^3, Shallow Water, Depth 3.5m

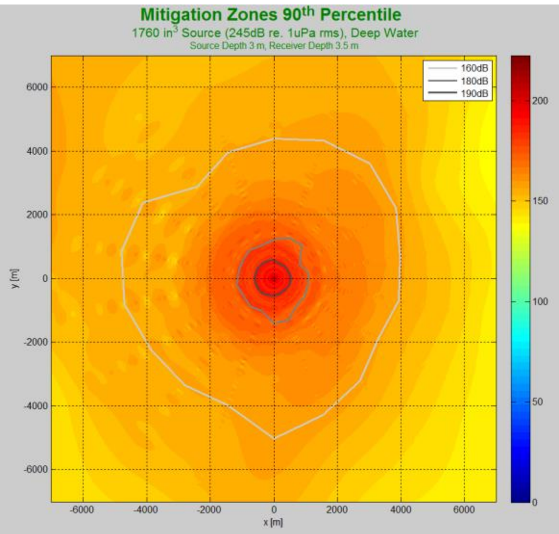


Figure 24 - Modelled Zone 1760 in^3, Deep Water, Depth 3.5m

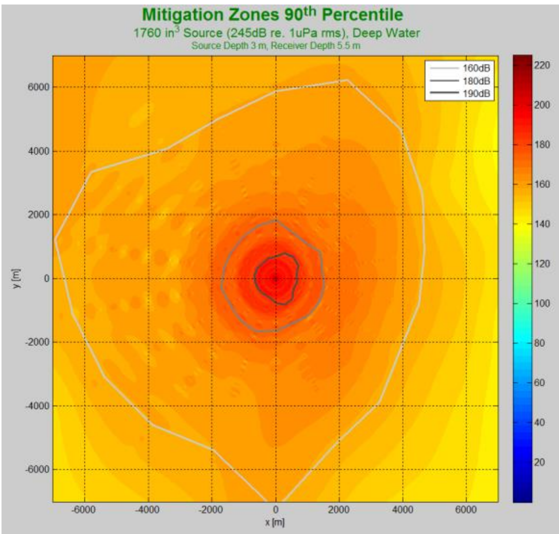


Figure 23 - Modelled Zone 1760 in^3, Deep Water, Depth 5.5m

	Modelled Distance in Metres for 90th percentile		
SPL$_{rms}$ Level dB re 1 μPa	**440 in^3**	**1760 in^3 Shallow Study**	**1760 in^3 Deep Study**
190 dB	50	830	880
180 dB	150	1530	1840
160 dB	1690	3280	7250

Table 5 - Modelled Maxima Zone Distances

7.1 Deep & Shallow Water Extents

In the preliminary report two mitigation zones were obtained from numerical modelling for the same source locations used in Cook Inlet deployment, one for shallow water (60.460254, -151.372638) and another one for deep water (60.507910, -151.574560). The mitigation zones extents are different when modelled at different water depths. In order to identify at which depth the transition between shallow and deep water behaviour occurs, further investigation have been undertaken.

To achieve this six models have been ran using six source positions along a line that starts and ends at the aforementioned shallow and deep water points (see Figure 25~30). The aim is to assess the variation of the exclusion zones at different source to seabed distances; the results will help us define the context at which a shallow or deep water mitigation zone should be used.

The distance between source points has been chosen to get 5 m depth steps in the initial positions (flat bathymetry) and 10 m depth steps in the last ones (steep slope). The SPL map and exclusion zones (see Figure 31~36) have been simulated considering a 90 Hz and 1760 in^3 seismic source, with receiver and source at 3 m depth. The environment parameters applied to the model have not been altered.

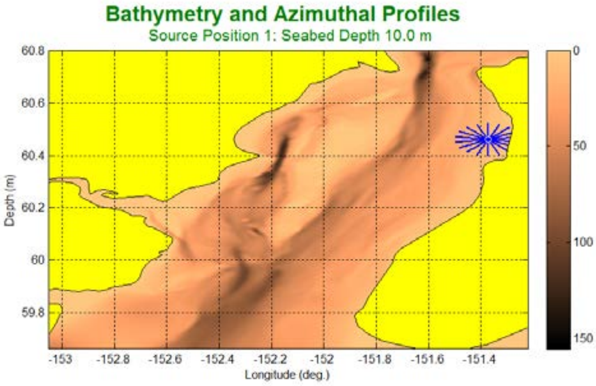


Figure 25 - Depth 10 m

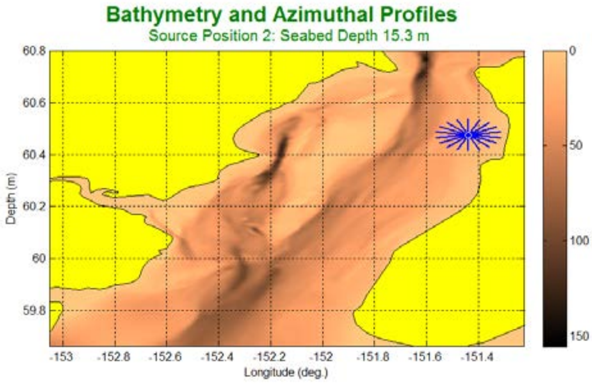


Figure 26 - Depth 15.3

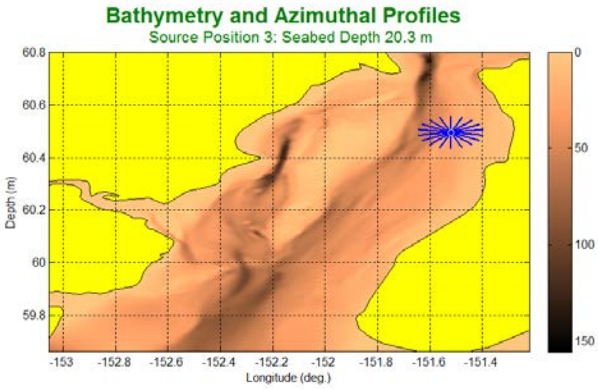


Figure 27 - Depth 20.3m

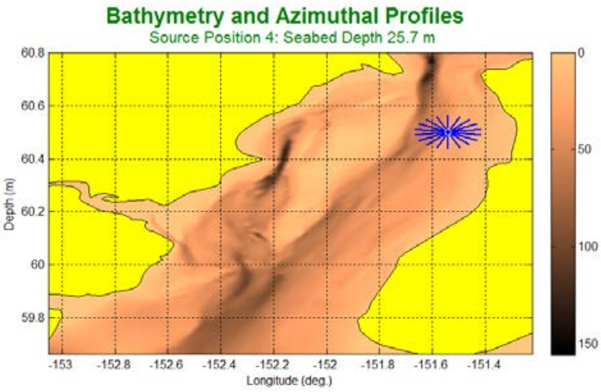


Figure 28 - Depth 25.7 m

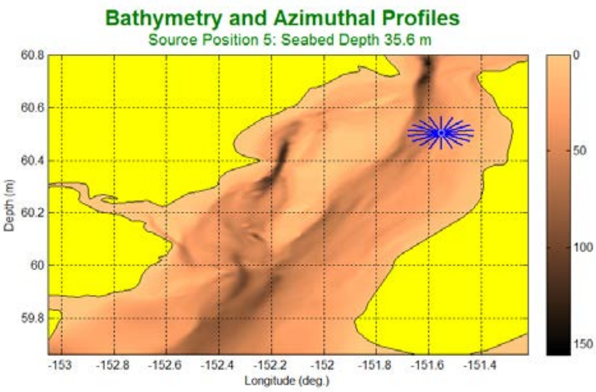


Figure 29 - Depth 35.6 m

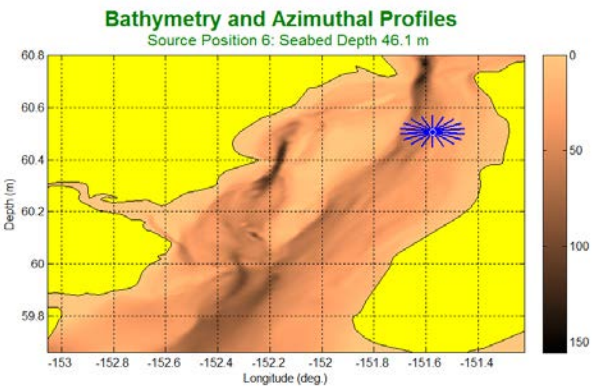


Figure 30 - Depth 46.1 m

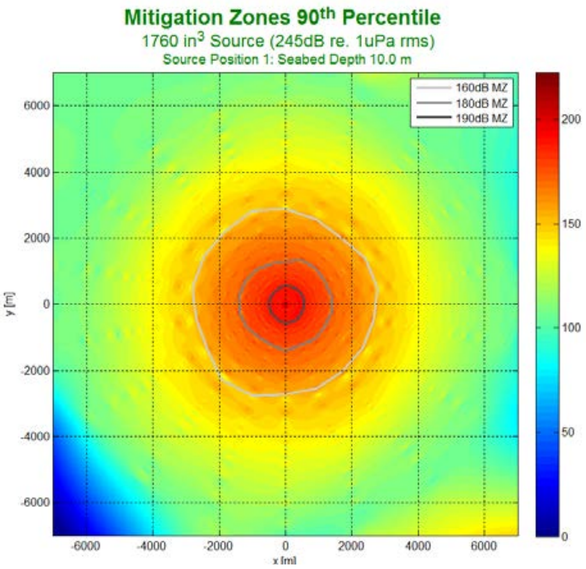


Figure 31 - Depth 15.3 m

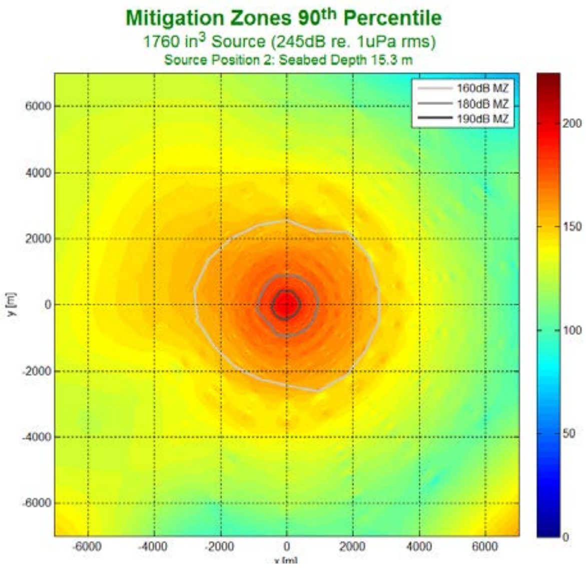


Figure 32 - Depth 10 m

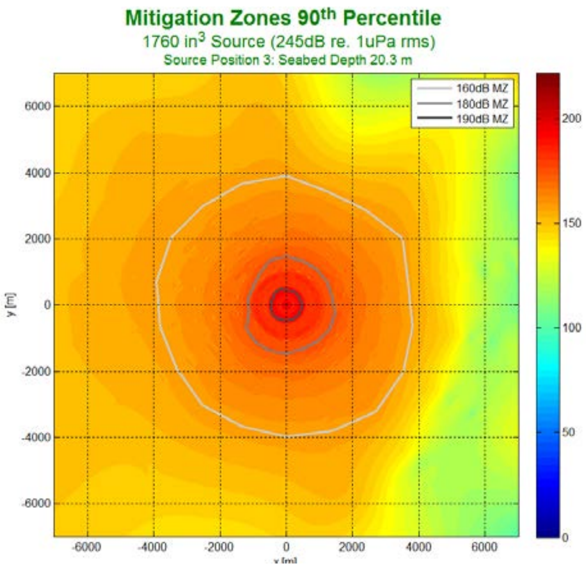


Figure 35 - Depth 35.6 m

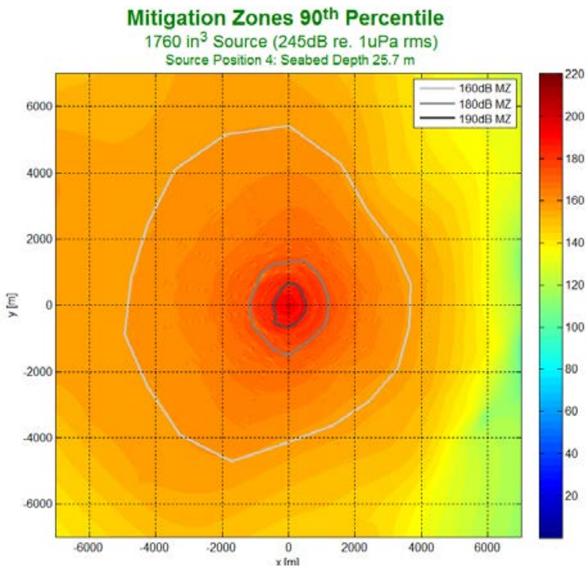


Figure 36 - Depth 46.1 m

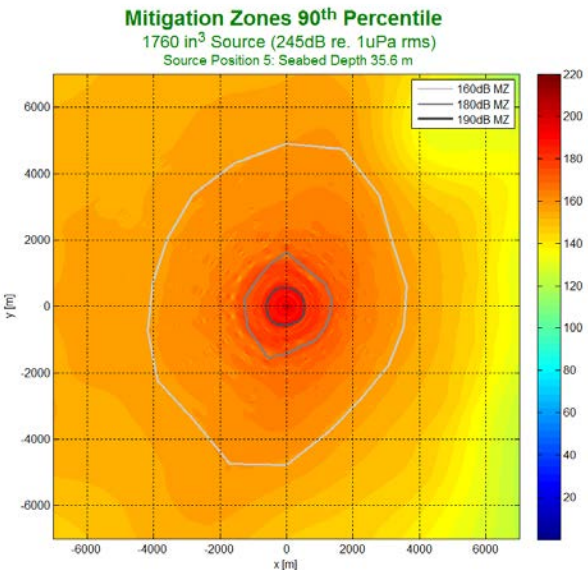


Figure 34 - Depth 25.7 m

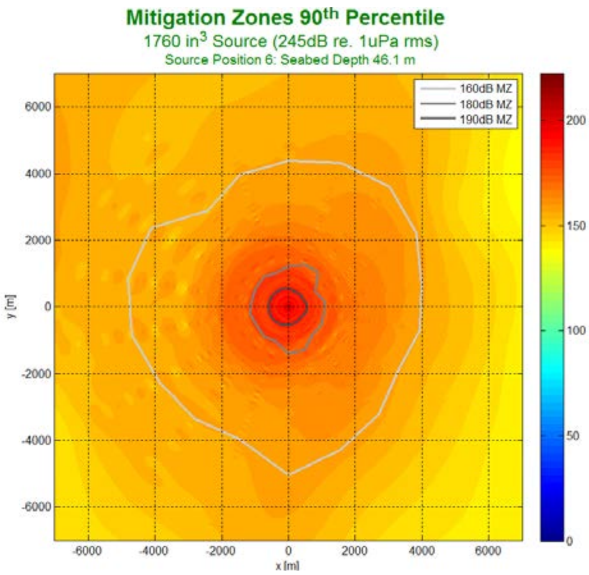


Figure 33 - Depth 20.3 m

Considering the results it can be clearly seen that there is strong relationship between the depth of the water column and the sound pressure level measured around the source. As the source moves towards the slope, the received amplitude increases. High sound pressure regions seem to originate in deep water is related with the main wavelength of the source. The size of the mitigation zone keeps fairly constant to depths of 15 m or less (see Figure 31 & 32) but above 15 m its size increases quickly, then keeps fairly constant above 25 m just with changes in shape due to the nature of the bathymetry. Then there is a transition point where the depth equals the source's fundamental frequency wavelength and from which the exclusion area experiences a big change.

According to these results it can be said that at depths above 15 m it should be applied the deep water mitigation zone and below 15 m the shallow water mitigation zone. This assumption is constrained by a few simulated points at a specific area of Cook Inlet, so is more a guideline than a general rule. The size of the exclusion zones will be affected by the particular bathymetry and seabed properties at each source point.

8 Conclusion

The nature of the deployment and data capture methodology ensured a wide, full and randomised data set. More than 13000 individual data points have been captured and analysed during this study. The results from the study are summarised in Table 6. The distances shown represent the maximum recommended zones for 160, 180 and 190 dB re 1 V/µPa sound levels based on the 90th percentile. There is a significant difference in the zone sizes between the 1760 in^3 arrays when deployed in shallow or deep water. The pre survey model has proven to provide a guide as to the expected zone requirements. Table 6 provides the zone data, where no valid data has been acquired then we have used the model to provide the values. These values are shown in italics Table 5.

	Distance in Metres for 90th percentile		
SPL_{rms} Level dB re 1 µPa	**440 in^3**	**1760 in^3 Shallow Study**	**1760 in^3 Deep Study**
190 dB	*50*	*830*	*880*
180 dB	182	*1530*	*1840*
160 dB	3050	4270	6830

Table 6 - Maximum Sound Threshold Distances

We would recommend the mitigation zones required are consistent with the levels shown in Table 6, particular attention should be taken of the shorter distances required for shallow water. It's expected that there is a correlation between the distances at shallow and deep water and as such the transition between these could be considered for a dynamic zone size.

As limited data was available in the 190 dB areas, futures deployments may need to take specific measures to ensure the buoys are close enough to the source.

It is proposed that in some cases the buoys could be released from or close to the source and allowed to drift away, how close to the source they need to be will be directly proportional to the source level.

Tables 7, 8 and 9 show the modelled results vs empirical measurements for the 80th, 90th and 95th percentile, respectively.

For each mitigation zone an error factor has been calculated to portray the accuracy of the model in comparison to the measured results. Values with '<' preceding a mitigation zone have been excluded as these results were estimates from the model.

Error values close to 1 portray excellent correlation between model and measure with value <1 represent where the model has overshot the measured results.

Each empirical and measured value is the maximum value found in the band of data.

It can be seen from the three tables that the error factor remains fairly consistent throughout the range of percentiles over a given study, with all three modelled percentiles over estimating the mitigation zone.

The error factor does seem to increase with mitigation zone level, however further investigations and measurements would need to be undertaken as limited empirical measurements exists for 190 dB mitigation zones.

The trend also seems to suggest that the error factor reduces for larger sources/deeper water, with all three percentiles displaying this response-note the much higher error factors are recorder with the $440in^3$ source.

Again further analysis would need to be made to confirm this.

	Modelled 80th percentile (m)			Measured 80th percentile (m)		
SPL_{rms} re 1 μPa	440 in^3	1760 in^3 Shallow Study	1760 in^3 Deep Study	440 in^3	1760 in^3 Shallow Study	1760in^3 Deep Study
190 dB	50	720	770	<50	<750	<850
180 dB	130	1440	1690	400	1451	2780
Error Factor	*3.078*	*1.007*	*1.65*			
160 dB	1610	3080	6670	2850	3580	6450
Error Factor	*1.77*	*1.161*	*0.967*			

Table 7 - Modelled vs Measured 80th Percentile

	Modelled 90th Percentile (m)			Measured 90th percentile (m)		
SPL_{rms} re 1 μPa	440 in^3	1760 in^3 Shallow Study	1760 in^3 Deep Study	440 in^3	1760 in^3 Shallow Study	1760 in^3 Deep Study
190 dB	50	830	880	<100	<850	<1000
180 dB	140	1530	1840	500	1514	2832
Error Factor	*3.57*	*0.99*	*1.54*			
160 dB	1790	3270	7250	3050	4270	6830
Error Factor	*1.70*	*1.30*	*0.94*			

Table 8 - Modelled vs Measured 90th Percentile

	Modelled 95th percentile (m)			Measured 95th percentile (m)		
SPL_{rms} re 1 μPa	440 in^3	1760 in^3 Shallow Study	1760 in^3 Deep Study	440 in^3	1760 in^3 Shallow Study	1760 in^3 Deep Study
190 dB	50	920	970	<150	<1000	<1200
180 dB	150	1610	1970	650	1543	2859
Error Factor	*4.33*	*0.95*	*1.45*			
160 dB	1940	3470	7720	3210	4600	7190
Error Factor	*1.65*	*1.33*	*0.93*			

Table 9 - Modelled vs Measured 95th Percentile

9 References

Ref: 1 - NOAA. (N/A). Bathymetry. Available: http://maps.ngdc.noaa.gov/viewers/bathymetry/index.html.

Ref: 2 - Application for Incidental Harassment Authorization", Apache Corporation.

Ref: 3 - Edwin L. Hamilton1. (1980). Geoacoustic modelling of the sea floor. J. Acoust. Soc. 68

Ref: 4 - Greene, C.R., Jr. 1997. Physical acoustics measurements. In W. J. Richardson (Ed.), Northstar marine mammal monitoring program, 1996

Ref: 5 - Robinson, S.P., Lepper, P. A. and Hazelwood, R.A. (2014). Good Practice Guide for Underwater Noise Measurement. NPL Good Practice Guide . No. 133

Ref: 6 - Needham,K.. (2010). Underwater noise propagation modelling and estimate of impact zones for seismic operations in the Moray Firth. . . FINAL REPORT 37399 – FR1 (C)

Ref: 7 - Bernard, P. (1975) . Leq, SEL, WHAT? WHY? WHEN?, Bruel&Kjaer Application Note.

Ref: 8 - NOAA. (2013). Draft Guidance for Assessing the Effects of Anthropogenic Sound on 14 Marine Mammals Acoustic Threshold Levels for Onset of Permanent and Temporary Threshold Shifts.

Ref: 9 - Pete Theobalda , Paul Lepper , Stephen Robinsona , Dick Hazelwooda. (2009). CUMULATIVE NOISE EXPOSURE ASSESSMENT FOR MARINE MAMMALS USING SOUND EXPOSURE LEVEL AS A METRIC

APPENDIX F

Comparison of Sound Source Verification for 1,760 in^3 and 2,400 in^3 Airgun Arrays

Appendix F: Comparison of Sound Source Verification for 1,760 in^3 and 2,400 in^3 Airgun Arrays

In 2014, Apache Alaska Corporation (Apache) conducted a Sound Source Verification (SSV) (full report in Appendix E) in Cook Inlet for a 1,760 cubic inches (in^3) airgun array in shallow and deep water locations. The results of the SSV (Table 1) indicate that the longest distance to 160 dB isopleth is 6.83 kilometer (km), measured in lower Cook Inlet. Table 2 details sound level thresholds for the 2,400 in^3 array measured in 2012. The greatest distance to the 160 dB isopleth for the 2,400 in^3 array measured 9.5 km, measured in upper Cook Inlet.

During 2012 SSV, Apache received daily acoustic footprints for the 2,400 in^3 array from JASCO Applied Sciences. However, the SSV conducted in 2014 Apache (by Seiche Measurements Ltd.) calculated the overall acoustic footprints, not daily, for the 1,760 in^3 array. Thus, Apache is unable to calculate daily ensonified areas and associated take estimates for the 1,760 in^3 array (that would be directly comparable to the 2,400 in^3 array). The different methodologies used in SSV between acoustic contractors would make for an inaccurate comparison between the two array sizes. Therefore, Apache did not calculate take estimates for the 1,760 in^3 array in this application, and proposes the take estimate as calculated for the 2,400 in^3 array. If the seismic data collected using the smaller array in 2014 is adequate for Apache and used again during the timeline of this Letter of Authorization, Apache will calculate take estimates for the 1,760 in^3 array. Seismic source array sizes and take estimates will be analyzed on an annual basis.

Table 1. Apache 1,760 in^3 airgun array Sound Source Verification

Sound Level Threshold (dB re 1 μPa)	Shallow (km)	Deep (km)
160 dB	4.27	*6.83*
180 dB	1.53	1.84
190 dB	0.83	0.88

Table 2. Apache 2,400 in^3 airgun array Sound Source Verification

Sound Level Threshold (dB re 1 μPa)	Water Depth at Source Location (m)	Distance in the Onshore Direction (km)	Distance in the Offshore Direction (km)	Distance in the Parallel to Shore Direction (km)
160	5	1.03	4.73	2.22
	25	5.69	7.77	*9.5*
	45	6.75	5.95	9.15
180	5	0.46	0.6	0.54
	25	1.06	1.07	1.42
	45	0.7	0.83	0.89
190	5	0.28	0.33	0.33
	25	0.35	0.36	0.44
	45	0.1	0.1	0.51