I-90 SNOQUALMIE PASS EAST

Underwater Sound Level Report: I-90 Keechelus Lake Avalanche Bridge Blasting

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ACRONYMS AND ABBREVIATIONS

dB	decibel
Hz	hertz
μPa	micro-Pascal
NIST	National Institute of Standards and Technology
Pa	Pascal
RMS	root mean squared
s.d.	standard deviation
SEL	Sound Exposure Level
SL	sound level, regardless of descriptor
SPL	sound pressure level
USFWS	U.S. Fish and Wildlife Service
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

This technical report describes the data collected during upland blasting and monitoring of underwater sound levels for the Washington State Department of Transportation (WSDOT) Interstate 90 (I-90) Phase 1C of the I-90 Snoqualmie Pass East Project, which includes highway improvements from MP 57.3 to MP 60.2, and replacement of the existing snowshed along Keechelus Lake with eastbound (EB) and westbound (WB) avalanche bridges.

To determine the effect of the avalanche bridges on Endangered Species Act (ESA) listed species and designated critical habitats, WSDOT has reinitiated consultation with the US Fish and Wildlife Service (Service) in 2012. The scope of the reinitiation was limited to analyzing the potential impacts of constructing, operating, and maintaining the bridges instead of the snowshed between MP 57.9 and MP 58.4. See vicinity map (Figure 1).

Underwater noise data was collected for blasts outside of the "Biological Opinion Area" and without the vent holes which occurred on two separate days, August 29, 2016 and September 8, 2016. August 29 range to the blast was 287 meters (942 feet) and the September 8 measurements were collected 257 meters (843 feet) from the blast location to maintain a safe distance and 10 meters from the water surface.

None of the monitored blasts exceeded the Root Mean Square (RMS) performance measure of 205 dB_{RMS} at the monitored location. The highest RMS sound levels measured ranged between 158 dB_{RMS} and 159 dB_{RMS}. Results of monitoring are shown in Table 1.

Table 1: Summary of Upland Blasting Underwater Sound Levels.

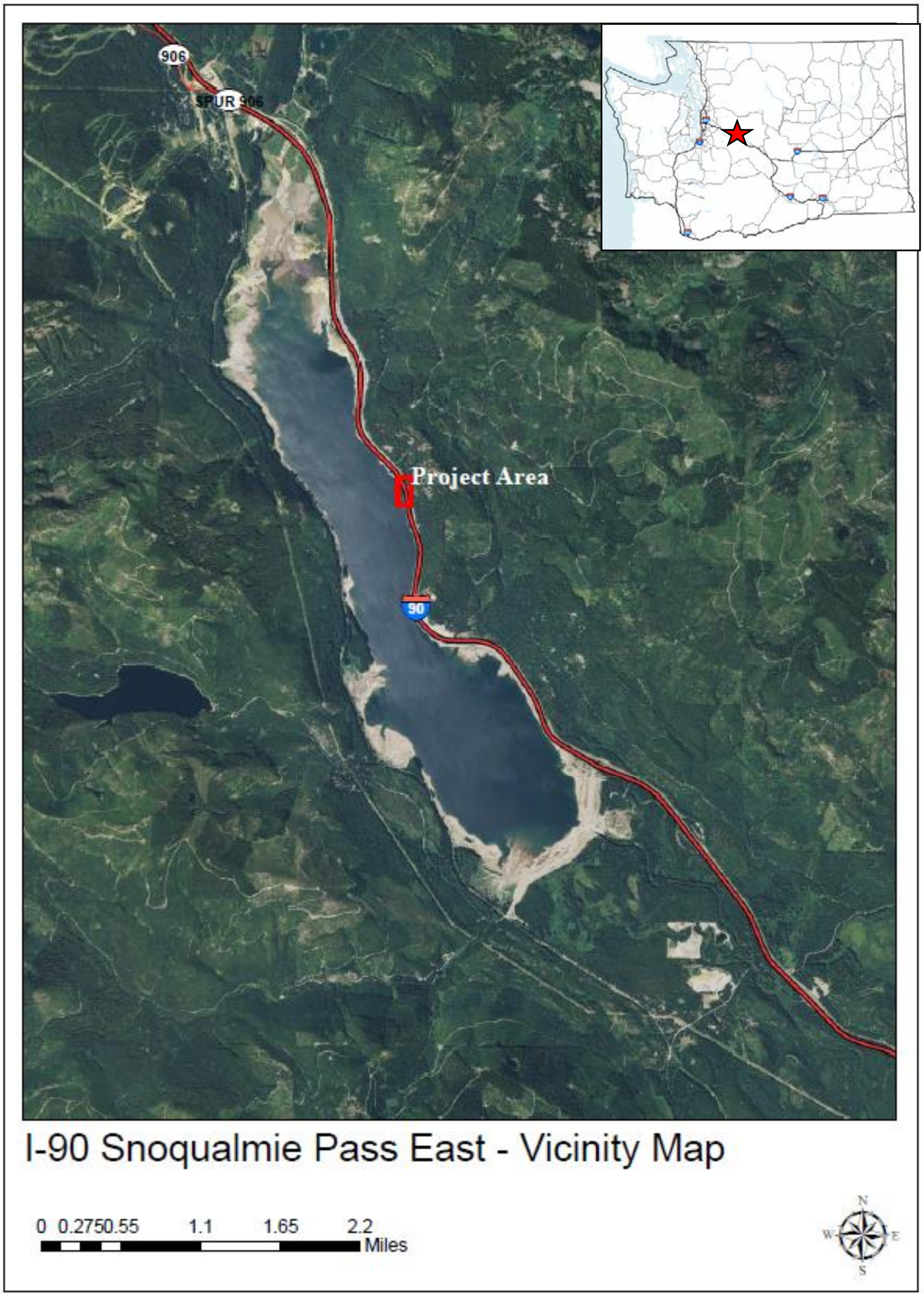
Date	Charge Weight (lbs)	Measurement Distance (meters)	RMS Performance Measure (dB)	Peak (dB)	RMS (dB)	SEL (dB)	Cumulative SEL (dB)	Exceedance Of Performance Measure at 1 meter from Shore?
8/29/16	7.5	287	205	167	158	150	154	No
9/8/16	30	257	205	170	159	152	157	No

INTRODUCTION

The Washington State Department of Transportation (WSDOT) is continuing construction of Phase 1C of the Interstate 90 (I-90) Snoqualmie Pass East Project, which includes highway improvements from MP 57.3 to MP 60.2, and replacement of the existing snowshed along Keechelus Lake with eastbound (EB) and westbound (WB) avalanche bridges.

To determine the effect of the blasting to create avalanche bridges on Endangered Species Act (ESA) listed species and designated critical habitats, WSDOT reinitiated consultation with the US Fish and Wildlife Service (Service) in 2012. The scope of the reinitiation was limited to analyzing the potential impacts of constructing, operating, and maintaining the bridges instead of the snowshed between MP 57.9 and MP 58.4. See vicinity map (Figure 1).

Figure 1: I-90 Snoqualmie Pass East Phase 1C



PROJECT AREA

Keechelus Lake is located in Kittitas County at the Snoqualmie Pass summit just west of I-90.

BLAST LOCATIONS

Blasting of consolidated material adjacent to Keechelus Lake for the excavation of the avalanche chutes has the potential to increase sound pressure levels in the lake. During consultation with the Service, WSDOT agreed to implement the following Conservation Recommendation to monitor underwater noise associated with blasting.

> *CR 6. Blasting near Keechelus Lake will provide an opportunity to learn about the effects of such activities on aquatic habitats and species. Development and implementation of a hydroacoustic monitoring program in the Lake during blasting could provide valuable information about the magnitude and extent of effects on bull trout and other species. This information could also be useful in the planning of future projects that require blasting near waters occupied by listed salmonids.*

In order to determine the extent of potential underwater impacts, the baseline or ambient noise level for Keechelus Lake was identified. WSDOT (2016) has identified underwater baseline noise levels at 50 dB_{RMS} for Keechelus Lake. However, 135 dB_{RMS} was assumed as baseline for Keechelus Lake in the consultation analysis.

Blasting below elevation 2,517 feet, on the lake side of the existing highway median, will adhere to minimization measures to ensure sound pressure levels are reduced as much as possible prior to entering the lake. Specifically, blast charge size and setback distances will be used to ensure blasting in adjacent bedrock will not produce sound pressure levels above 100 kilopascals, or 220 dB_{peak} at 1 meter (3 feet) from the shore within the lake. A misinterpretation occurred in the Biological Opinion (BO) indicated that 100 kilopascals equals 194 dB as measured in air, however, underwater 100 kilopascals is actually 220 dB. A conservative rule of thumb to convert peak dB to RMS dB is to subtract 15 dB. Therefore, subtracting 15 dB from 220 dB_{peak} results in an estimated 205 dB_{RMS} maximum underwater sound pressure levels generated by blasting at 1 meter (3 feet) from the shore. This also resulted in an incorrect estimate of where the sound levels would attenuate to 150 dB_{RMS}. Based on these updated calculations the sound levels would attenuate to 150 dB_{RMS} at 4.4 kilometers (2.9 miles) from the shoreline which means it would encounter land on the opposite side of the lake before reaching 150 dB_{RMS}.

In addition to limiting charge sizes based on distance to water, vent holes will be drilled between the blast zone and Keechelus Lake. Though it is not known how much these vent holes will reduce sound pressure levels, it can be assumed they will function similarly to bubble curtains which are used in water to introduce a change in media through which sound must travel. WSDOT (2010) has used a conservative estimate based on hydro-acoustic monitoring that bubble curtains result in at least a 10 dB reduction in sound pressures. Research on blasting documents a 60 to 80 percent reduction in peak particle velocities when vent holes are used. Because exact sound reduction levels are not known, this assessment will use the conservative un-attenuated sound pressure level of 205 dB_{RMS} as the maximum underwater sound pressure level within Keechelus Lake. However, significant decreases in sound pressure levels are likely as a result of planned minimization measures.

- Measurement of noise levels were at 287 and 257 meters from the blast.

Figure 2 indicates the approximate location of the blast and hydrophone during monitoring. The hydrophone was placed at least 10 m (33 feet) below the water's surface at a range of 287 meters (942 feet) on August 29 and a range of 257 meters (843 feet) on September 8.

Figure 2: Hydrophone location relative to the upland blast area

UNDERWATER SOUND LEVELS

Characteristics of Underwater Sound

Several descriptors are used to describe underwater noise impacts. Two common descriptors are the instantaneous peak sound pressure level (SPL) and the Root Mean Square (RMS) pressure level during the impulse. The peak SPL is the instantaneous maximum or minimum overpressure observed during each pulse and can be presented in Pascals (Pa) or decibels (dB) referenced to a pressure of 1 micropascal (μPa). Since water and air are two distinctly different media, a different sound level reference pressure is used for each. In water, the most commonly used reference pressure is 1 μPa whereas the reference pressure for air is 20 μPa. The majority of literature uses peak sound pressures to evaluate barotrauma injury to fish. Except where otherwise noted, sound levels reported in this report are expressed in dB re: 1 μPa. The equation to calculate the sound pressure level is:

Sound Pressure Level (SPL) = 20 log (p/p_{ref}), where p_{ref} is the reference pressure (i.e., 1 μPa for water)

The RMS level is the square root of the energy divided by the impulse duration. This level, presented in dB re: 1 μPa, is the mean square pressure level of the pulse. It has been used by the National Marine Fisheries Service (NMFS) in criteria for judging effects to marine mammals from underwater impulse-type sounds.

One-third octave band analysis offers a more convenient way to look at the composition of the sound and is an improvement over previous techniques. One-third octave bands are frequency bands whose upper limit in hertz is $2^{1/3}$ (1.26) times the lower limit. The width of a given band is 23% of its center frequency. For example, the 1/3-octave band centered at 100 Hz extends from 89 to 112 Hz, whereas the band centered at 1000 Hz extends from 890 to 1120 Hz. The 1/3-octave band level is calculated by integrating the spectral densities between the band frequency limits. Conversion to decibels is:

dB = 10*LOG (sum of squared pressures in the band) (eq. 1)

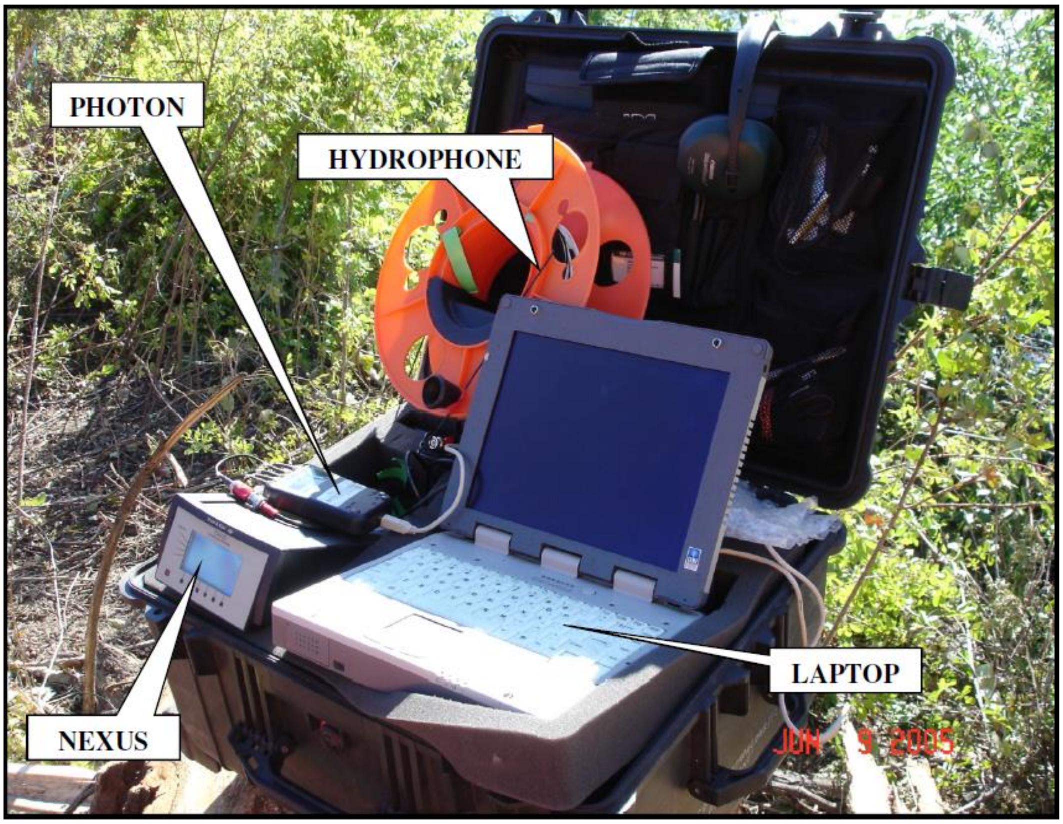
Sound levels are often presented for 1/3-octave bands because the 1/3rd octave bands are proportional to frequency and often about 1/3-octave. In other words, a perception of a sound at a given frequency will be strongly affected by other sounds within a 1/3-octave band around that frequency. The overall level (acoustically summing the pressure level at all frequencies) of a broadband (20 Hz to 20 kHz) sound exceeds the level in any single 1/3-octave band.

METHODOLOGY

Typical Equipment Deployment

The hydrophone was deployed from a moored boat at a range of 287 meters (942 feet) from the blast on August 29 and a range of 257 meters (843 feet) from the blast on September 8. The monitoring equipment is outlined below and shown in Figure 3. The hydrophone was deployed from the side of the boat, 10 meters (33 feet) below the water surface, with the boat motor off.

Figure 3: Near Field Acoustical Monitoring Equipment



Underwater sound levels were measured during the blast using a Reson TC 4013 hydrophone deployed on a weighted nylon cord from the monitoring location. The measurement system includes a Brüel and Kjær Nexus type 2692 4-channel signal conditioner, which kept the high underwater sound levels within the dynamic range of the signal analyzer, shown in Figure 3. The output of the Nexus signal conditioner is received by a Brüel and Kjær Photon 4-channel signal spectrum analyzer that is attached to a Dell ATG laptop computer similar to the one shown in Figure 3.

The equipment captures underwater sound levels from the pile driving operations in the format of an RTPro signal file for processing later. The WSDOT has the system and software calibration checked annually against NIST traceable standard.

Signal analysis software provided with the Photon was set at a sampling rate of one sample every 15.3 μs (25,600 Hz). This sampling rate provides sufficient resolution to catch the peaks and other relevant data. The anti-aliasing filter included in the Photon also allows the capture of the true peak.

A performance measure of 205 dB_{RMS} at 1 meter (3 feet) from the shore was applied to this project.

RESULTS

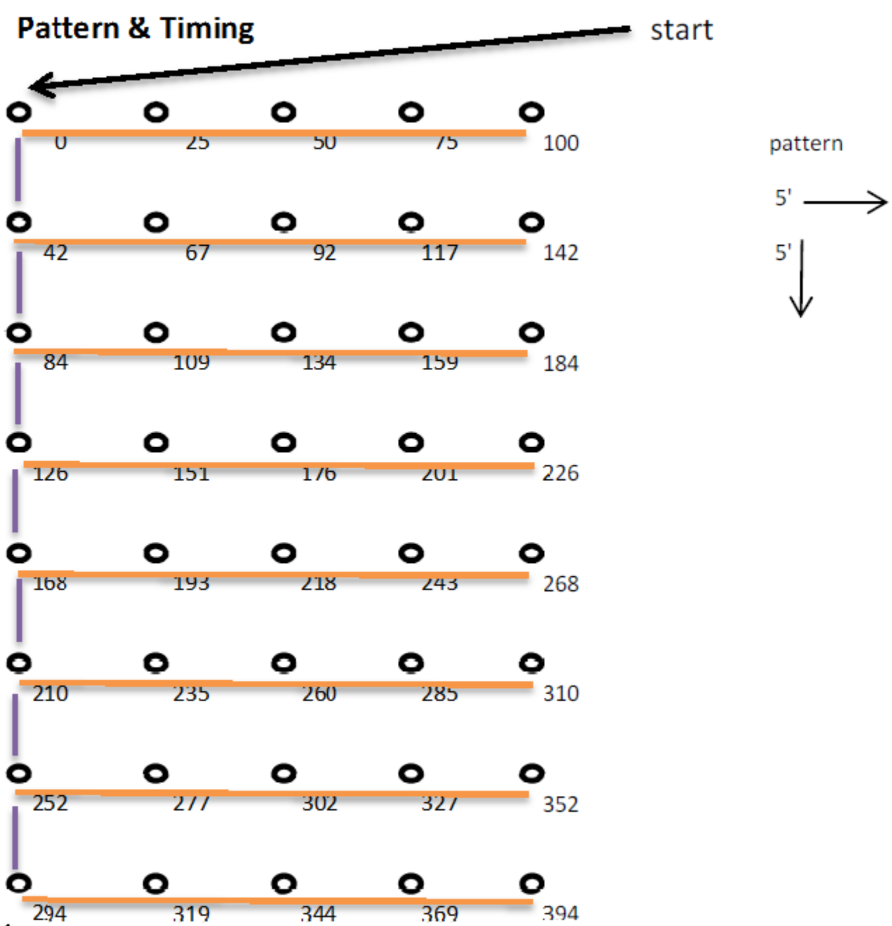
Underwater Sound Levels

WSDOT monitored two upland blast events for underwater noise. Data from the blast events are analyzed in the paragraphs and figures below and summarized in Table 2.

August 29 Blast

The first preliminary controlled blast is above and behind the elevation that the Biological Opinion takes effect (governed by distance from water's edge) and had all holes at 3-inch diameter and loaded with ANFO (ammonium nitrate fuel oil) explosive. There was a maximum of 7.5 lbs. charge per delay period of 8 ms which gives a maximum lb. per delay for production of 7.5 lbs. The timing was 25 X 42 ms between spacing and rows. There were no duplications in the 5 rows wide, 7-hole long pattern. The pattern was 5 X 5 feet, burden and spacing. This is an "echelon" type pattern. The starting of the blast (uphill side) was covered with heavy mats. The holes were 10 feet deep with 7 feet stemming with a 3-foot maximum load of ANFO or packaged emulsion in wet holes. See Figure 4. No vent holes were drilled to attenuate the sound traveling through rock.

Figure 4: Blast Pattern Diagram for First Preliminary Blast



The measured blast had an absolute peak value of 167 dB_{peak} at 287 meters (942 feet). The highest $RMS_{90\%}$ was measured at 158 dB_{RMS}. The distance from the measurement location to 1 meter (3.3 feet) from the shoreline and the performance standard is 196 meters (643 feet). The measured blast at 1 meter from the shoreline calculated using the practical spreading model was 160 dB_{RMS} and did not exceed the 205 dB_{RMS} performance measure. The cSEL was calculated to be 154 dB_{SEL} at 287 meters (942 feet). The distance to 150 dB_{RMS} is 1,176 meters (3,858 feet) from the shoreline.

September 8 Blast

The second preliminary controlled blast was closer to the shoreline than the blast on August 29 and still over 150 feet from the water's edge. This blast is shown as 3 rows wide (Figure 6). All the production holes were 3 inches diameter and loaded with ANFO, Water Resistant-ANFO and cartridge emulsion in the bottom of the wettest holes. The maximum hole load was 30 lbs. The blast started at the N.E. corner and was timed to move to the north. The timing was 25 X 84 ms and there were no timing duplications in the production less than 8 ms. The last row was the 3rd row from the start and was decked with two 7.5 lb. charges with 25 ms between the top and bottom charge. Maximum pounds per delay was 30 lbs. Matting was used on the starting row location.

The measured blast had an absolute peak value of 170 dB_{peak} at 257 meters (843 feet). The highest $RMS_{90\%}$ at 257 meters (843 feet) was measured at 159 dB_{RMS}. The distance from the measurement location to 1 meter from the shoreline and the performance standard is 196 meters (643 feet). The measured blast at 1 meter (3.3 feet) from the shoreline calculated using the practical spreading model was 161 dB_{RMS} and did not exceed the 205 dB_{RMS} performance measure. The cSEL was calculated to be 157 dB_{SEL} at 257 meters (843 feet). The distance to 150 dB_{RMS} is 1,219 meters (3,999 feet) from the shoreline.

Figure 5: Blast Pattern Diagram for Second Preliminary Blast

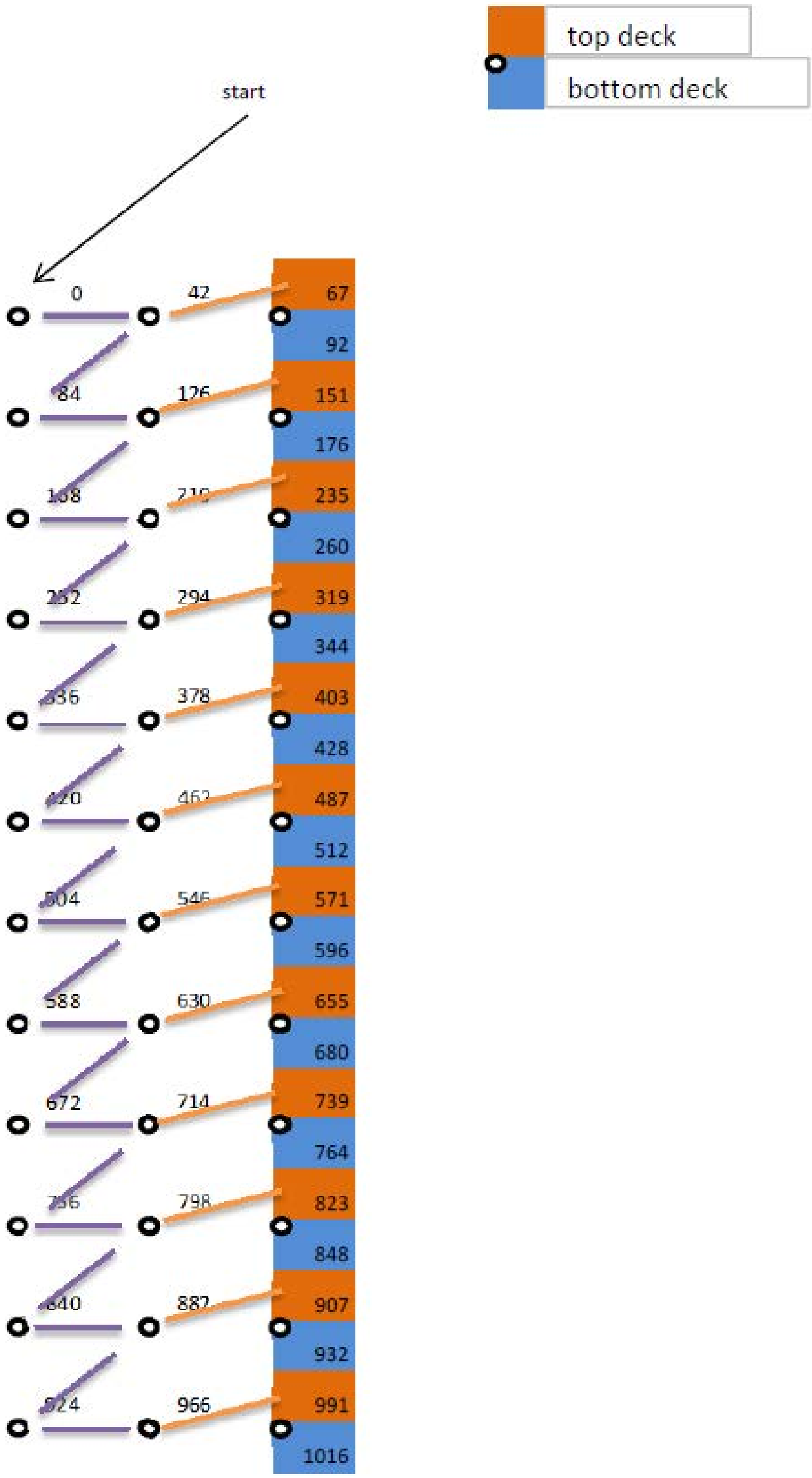


Table 2: Summary of Underwater Broadband Sound Levels for the I-90 Snoqualmie Pass East Blasting

Date	Charge Weight (lbs)	Hydrophone Range (m)	$RMS_{90\%}$ Performance Measure At 1 meter	Hydro phone Depth (feet)	Highest Absolute Peak (dB)	$RMS_{90\%}$ (dB)	$SEL_{90\%}$ (dB)	Avg. Peak ± s.d. (Pascal)	Avg. RMS ± s.d. (Pascal)	Cumulative SEL (dB)
8/29/16	7.5	287	205	33	167	158	150	122±39	87±35	154
9/8/16	30	257	205	33	170	159	152	131±63	93±51	157

Daily Cumulative SEL

The daily cSEL's were calculated using an actual $SEL_{90\%}$ for each individual blast for each day and accumulated over that period (Table 3).

Table 3: Summary of daily cumulative SEL's

Day	cSEL
8/29/16	154
9/8/16	157

The daily cumulative SEL values ranged from 154 dB_{cSEL} to 157 dB_{cSEL} at the monitored location.

Propagation and Charge Weights

The measured peak, RMS90% and Sound Exposure Level (SEL90%) for the August 29 and September 8 blasts are shown in Figures 6 and 7. The red dashed line represents the 205 dB_{RMS} performance measure and none of the RMS90% values exceeded the performance measure at a distance of 287 meters (942 feet) on August 29 and 257 meters (843 feet) on September 8. The peak values did not exceed 220 dB_{peak} at 1 meter (3.3 feet) from the shoreline and are more variable because they represent only one single point in time whereas the RMS and SEL are calculated over time.

Figure 6: August 29 Blast Peak, RMS90% and SEL90% Over Time Measured at 287 meters

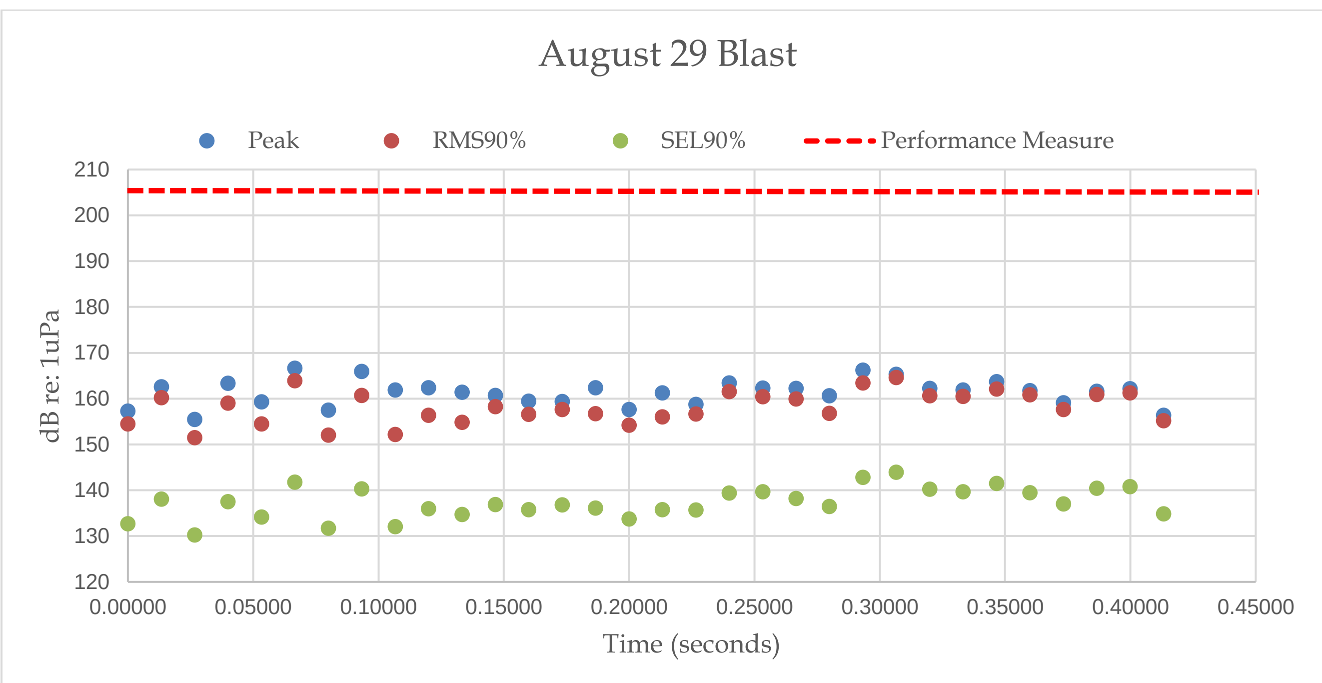


Figure 7: September 8 Blast Peak, RMS90% and SEL90% Over Time Measured at 257 meters

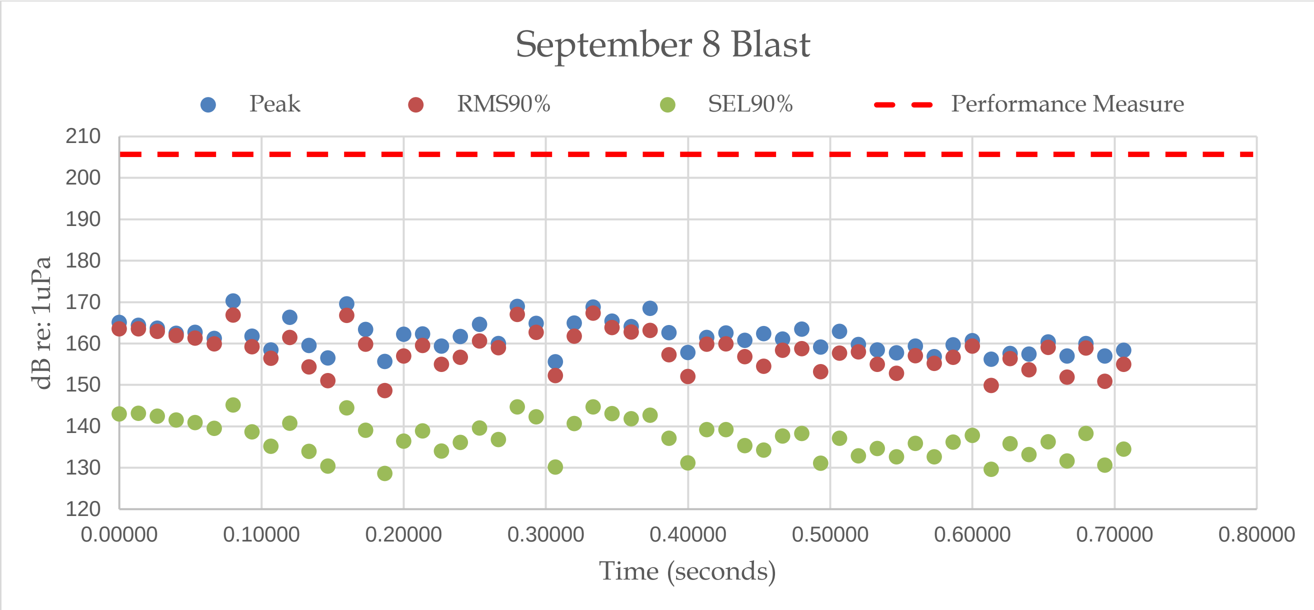


Figure 8 shows the predicted attenuation over distance assuming an RMS value of 205 dB at 1 meter from the shoreline (green line). The actual measured attenuation is represented by the measured values (blue and red circles) and the attenuation based on the measured data (blue and red lines). The August 29 blast was approximately 30 meters further from the monitoring site and so attenuates a little more over distance. The measured sound levels at 1 meter (3.3 feet) from the shoreline are below the 205 dB RMS performance measure.

Figure 8: August 29 and September 8 Blasts RMS90% Attenuation Over Distance

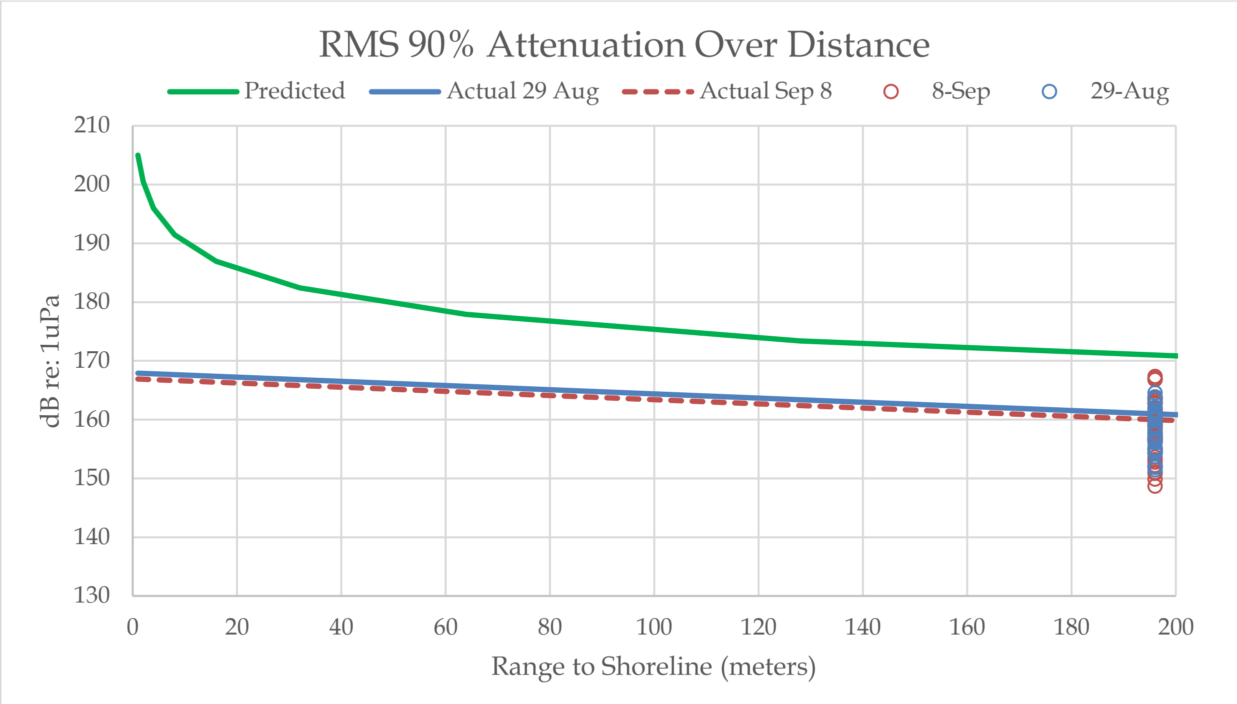
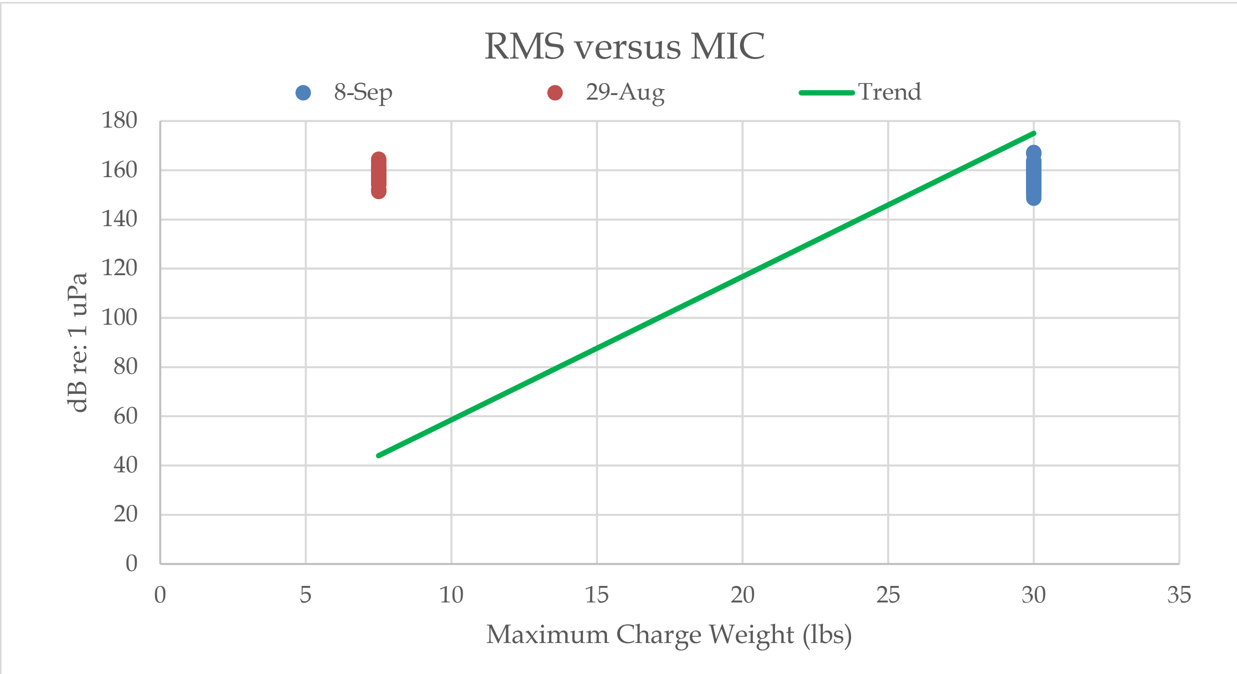


Figure 9 shows the measured blast noise levels versus the charge weight as the Maximum Instantaneous Charge (MIC) or maximum weight of explosive per delay interval in lbs. The MIC for the August 29 blast was 7.5 pounds and 30 pounds for the September 8 blast. The green trend line shows an increasing noise level with increasing MIC.

Figure 9: September 8 Blast Peak, RMS90% and SEL90% Over Time



Calculation of Setback Distance

Guidelines published by the Canadian Department of Fisheries and Oceans for protection of spawning fish from explosives (Wright and Hopky, 1998), were used in the Biological Assessment and Opinion. They provide the following formula for calculating the setback distance for fish.

$$R = W^{.5}(K)$$

Where:

R = distance to the detonation point in meters

W = charge weight per delay in kilograms

K = factor that represents peak particle velocity in rock (4.173)

Using the charge weight of 7.5 pounds (3.4 kg) for the August 29 blast and 30 pounds (13.6 kg) for the September 8 blast generates a setback distance of 25 feet and 75 feet respectively. Since each blast was over 150 feet from the shoreline they were well beyond a safe setback distance.

CONCLUSIONS

Two preliminary blasts above and further upland from the Biological Opinion Zone were monitored for underwater noise levels to validate the assumptions in both the Biological Assessment and Opinion.

August 29 blast:

- The blasts did not exceed the 205 dB_{RMS} performance measure at 1 meter (3.3 feet) from the shoreline.
- The blasts did not exceed 220 dB_{peak} at 1 meter (3.3 feet) from the shoreline.
- Peak underwater un-attenuated sound level at 287 meters (942 feet) is 167 dB_{peak} and 169 dB_{peak} at 1 meter from the shoreline.
- The measured $RMS_{90\%}$ level at 287 meters (942 feet) is 158 dB_{RMS} and 160 dB_{RMS} at 1 meter from the shoreline.
- Cumulative Sound Exposure Levels (cSEL) for August 29 at 287 meters (942 feet) is 154 dB_{cSEL}.
- Distance from the shoreline to 150 dBRMS is 1,176 meters (3,858 feet).

September 8 blast

- The blasts did not exceed the 205 dB_{RMS} performance measure at 1 meter (3.3 feet) from the shoreline.
- The blasts did not exceed 220 dB_{peak} at 1 meter (3.3 feet) from the shoreline.
- Peak underwater un-attenuated sound level at 257 meters (843 feet) was 170 dB_{peak} and 172 dB_{peak} at 1 meter from the shoreline.
- The measured un-attenuated $RMS_{90\%}$ level measurement at 257 meters (843 feet) is 159 dB_{RMS} and 161 dB_{RMS} at 1 meter from the shoreline.
- Cumulative Sound Exposure Levels (cSEL) for September 8 at 257 meters (843 feet) is 157 dB_{SEL}.
- Distance from the shoreline to 150 dBRMS is 1,219 meters (3,999 feet).

REFERENCES

Wright, D.G., and G.E. Hopky. 1998. Guidelines for the use of explosives in or near Canadian fisheries waters. Can. Tech. Rep. Fish. Aquat. Sci. 2107: iv + 34p.

APPENDIX A WAVEFORM ANALYSIS FIGURES

Figure 10: Waveform Analysis of August 29th Blast, 287M (942 feet)

August 29 Keechelus Lake Blasting at 287m Broadband

Figure a. Waveform

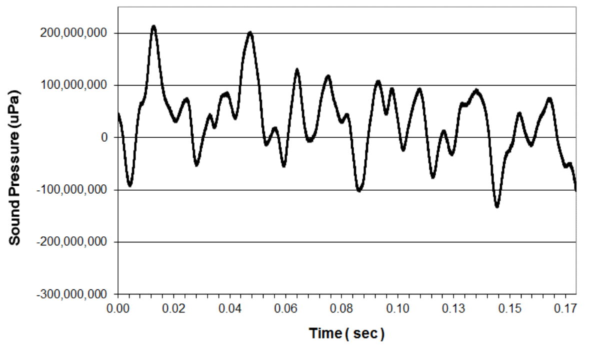


Figure b. Narrow Band Frequency Spectra

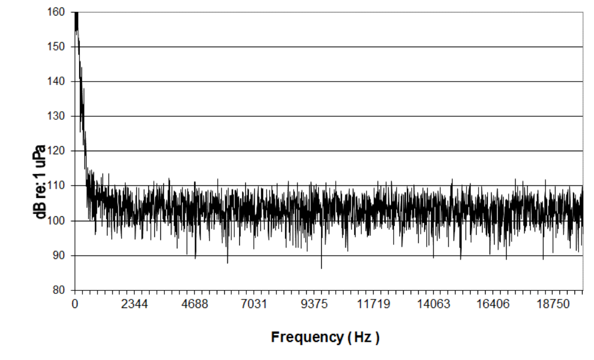


Figure c. Accumulation of Sound Energy

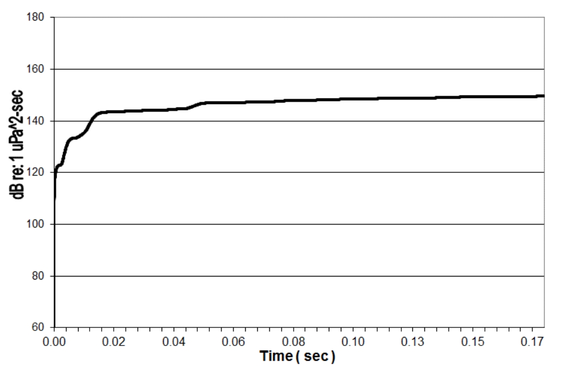


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
33-feet	167	158	150

*Impulse averaged over 90% of accumulated energy (5% to 95%)

Figure 11: Waveform Analysis of September 8th Blast, 257M (843 feet)

September 8 Keechelus Lake Blasting at 257m Broadband

Figure a. Waveform

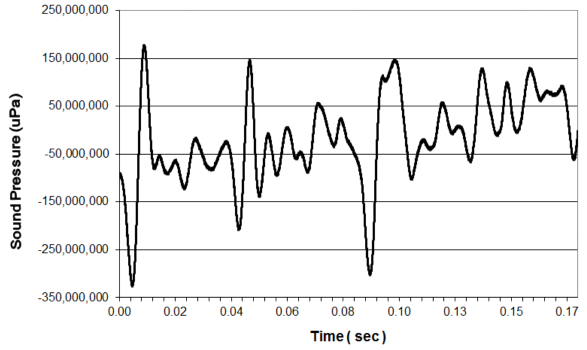
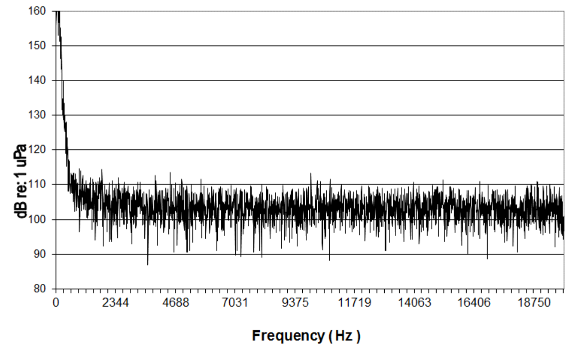


Figure b. Narrow Band Frequency Spectra



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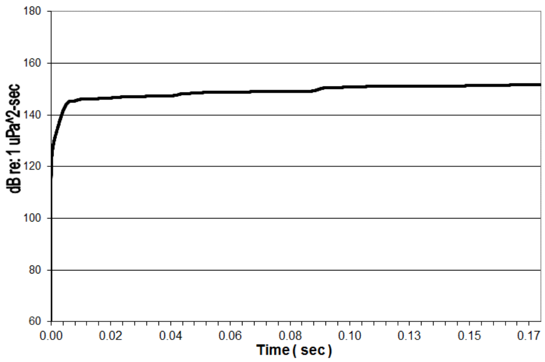

Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Sensor Depth	Peak	RMS90%*	SEL
33-feet	170	159	152

*Impulse averaged over 90% of accumulated energy (5% to 95%)