APPENDIX G-5

NOISE MODELING REPORT

Acoustic Analysis of Potential Impacts from Covering Live-fire Training and Combined Arms Live-fire Exercises (CALFEX) at the Makua Military Reservation (MMR)

Prepared For:
Tetra Tech, Inc.
820 Mililani Street, Suite 700
Honolulu, Hawaii 96813

Under Tetra Tech Subcontract Number: 2004-6

MAI-491-U-05-024
23 February 2005

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Research – Operations – Engineering – Design - Analysis

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Executive Summary

This report consists of a noise analysis of the Army's Makua Military Reservation (MMR) during live firing training and Combined Arms Live-Fire Exercises (CALFEX). The objectives were: to predict Received Levels (RLs) during live firing and helicopter over-flight operations at selected sites, and to analyze the impact on in-water marine mammals from these same operations. Five spatial positions were selected to document the predicted noise levels in and near the ocean. They included three terrestrial positions on/near the beach and two in-water locations. The scenario assumed for this analysis includes: a) the firing of howitzers, mortars, and small arms, b) the detonations of projectiles, and various weights of high explosives, and c) helicopter operations over land. Helicopter operations include the use of three different models of helicopters.

As a reference point to the received levels predicted in this report, the Marine Mammal Protection Act (MMPA) (i.e., one of the primary United States' law applicable to protecting marine mammals) as modified slightly by the National Defense Authorization Act (NDAA) of 2004, was identified as establishing the definitions of Level A and Level B harassment. For the purposes of this document, the specific criteria and calculation techniques utilized in the "Final Environmental Impact Statement (FEIS) for Shock Testing *Seawolf* Submarine" and "Final Environmental Impact Statement Shock Testing *U.S.S. Churchill"* (DoN 1998 and 2001) to estimate Level A and Level B harassment were replicated here.

These calculations included: 1) source level (SL) estimation based on standard explosive similitude equations and Net Explosive Weight (NEW) for the ordnance, and measured values for gunnery fire, and helicopter levels, 2) acoustic propagation models (specifically, the Navy Standard Comprehensive Acoustic System Simulation (CASS) / Gaussian Ray Bundle (GRAB) model) for in-air and in-water transmission loss (TL) estimation, and 3) utilization of the best available data from the Navy standard underwater acoustic databases and atmospheric data from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). The results from the atmospheric, underwater, and seismic propagation model include acoustic ray and TL plots for each source/receiver site combination. The specific TL for each receiver site was then identified and convolved with the SLs for each of the sources. The resulting received levels at each site for each source were then documented.

In conducting this analysis, the best available scientific, environmental, geologic, and meteorological data were obtained and used to calculate the TLs and subsequently to predict the RLs at the five receiver sites. Additionally, throughout this analysis, conservative assumptions were made. Therefore, the results presented here do not represent the full range of TL, which could occur, but an estimate of the typical nominal minimum TL (and therefore nominal maximum RLs) that can be expected for most days throughout the year. The results are not a "worst case" result, because there could be cases with stronger near-ground cooling or wind conditions which could increase the RLs, but days with these conditions would be infrequent and only represent an estimated 10-15 dB higher RL. Similarly, environmental conditions could greatly increase the TL and reduce RLs, and effectively make the noise from the modeled sources indistinguishable from ambient noise.

The estimated nominal, but conservative RLs for the individual sources show that the criteria for Level A or Level B harassment of marine mammals were never approached by these RLs at the in-water hydrophone or at any of the receiver sites, even for the largest sources. In fact, they were nominally 50 dB or more below even Level B thresholds and many were less than ambient noise level estimates for the MMR area. Effectively this means that many of the operations or sources would not be heard over the ambient noise. Additionally, planned helicopter operations resulted in RLs at the in-water receivers that were at worst only slightly higher than ambient noise levels. Therefore, it is highly unlikely that marine mammals potentially present offshore of MMR would be impacted by a single or multiple CALFEXs at the MMR.

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U.S. Army Makua Reservation Acoustic Modeling and Analysis

1.0 BACKGROUND

This report consists of a noise analysis of the Army's Makua Military Reservation (MMR) during live firing training and Combined Arms Live-Fire Exercises (CALFEX). The MMR is shown in the map below, Figure 1-1. The objectives were: to predict peak noise levels during live firing and helicopter over-flight operations at selected sites, and to analyze the impact on in-water marine mammals from these same operations. Five spatial positions were selected to document the predicted noise levels, three positions were terrestrial and two were in the water near the beach of the military reservation. Hereafter these five sites will be referred to as the receiver sites and they are shown in Figure 1-1. For this figure only, "receiver site" is abbreviated as "RCV." Additionally, the source locations are identified in this figure and abbreviated as "SRC."

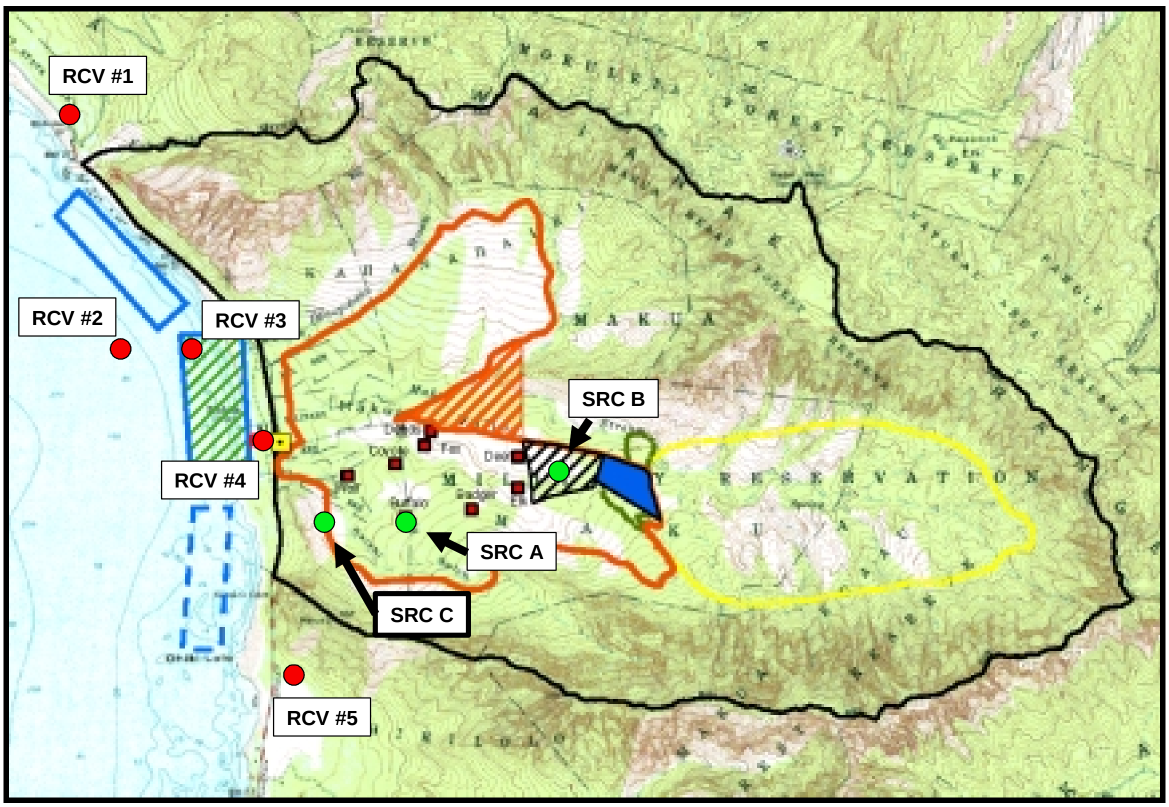

Figure 1-1 Map of MMR Exercise Site

The five receiver sites were selected so that a) the model results would predict in-air receive levels (RLs) on the beach in the vicinity of MMR and b) the in-air and in-water RLs for two selected measurement sites were examined. Receiver site #1 is a beach site approximately 500 ft north of MMR in the state park. Receiver site #2 is the offshore measurement hydrophone and microphone location, which is about 1,000 ft offshore. Receiver site #3 is the near shore measurement hydrophone and microphone location, which is about 200 ft offshore. Receiver site #4 is the former N1 site and it is on the beach approximately midway between the north and south maximum extent of the MMR on the coast. Receiver site #5 is the former N5 site and it is on the beach approximately 800 ft south of the MMR. Thus Receiver sites #1, 4 and 5 can be used to predict the in-air RLs at three beach locations, which are north, inside and south of MMR. Receiver sites #2 and 3 are the locations of the offshore measurement hydrophones and microphones.

The scenario assumed for this analysis includes: a) the firing of howitzers, mortars, and small arms from source area “A” (shown as “SRC A” in Figure 1-1), b) the detonations of projectiles, and various weights of high explosives in source area “B,” and helicopter operations in source area “C.” Helicopter operations include the use of three different models of helicopters. This analysis was directed toward arriving at the maximum RL that would be measured at each of the five receiver sites as a function of each individual event. For multiple events occurring at the same time, the individual RLs can be summed across events using standard acoustic engineering techniques for the addition of decibels.

In order to conduct this analysis, source levels for the howitzers, mortars, missiles, small arms, and high explosive detonations must be established. These source levels have been documented by many measurements in the field and are readily available. On the other hand, helicopter source levels are dependent on the blade loading, velocity, and other operating factors and must be estimated for each operating mode (e.g., max range cruise, hover, etc.). A range of source levels can be predicted for each helicopter type for each assumed mode of operations and fortunately a range of noise levels have been measured in the past and are available in the literature for comparison. By custom, source levels are designated at a range of one meter (m) (3.28 ft) from the noise source (e.g., 1 m from the gun muzzle, 1 m from the center of the detonation for a projectile, 1 m from the helicopter blade hub, etc.)

After source levels for each event are established, the potential paths for sound transmission must be estimated from the point of origin to the five sites where the RLs are to be determined. For gun firings, the transmission paths consist of a set of paths from the muzzle, via the air, and to each site; a set of paths from the gun chamber and barrel, via the gun structure, the soil, rock, water or air and to the data site, and so on for each event. Each path has a loss of sound intensity associated with it and this loss is dependent upon many physical properties of the medium be it the air, soil, rock, sediments, or water. The establishment of a reasonable range for the physical properties of the propagation medium must be completed and input into standard, verified computer models in order to estimate the loss in sound level associated with each propagation path. For most areas of the world, a range of values is available to estimate the value of physical parameters by season of the year. For this analysis, published parameters for meteorological, geological, and vegetation cover were used as inputs into acoustic propagation models.

1.1 Units

A short discussion on units is in order to prevent confusion between "in-air" units and "in-water" units and "weighted" and "un-weighted" decibels. Decibels (dB) have by custom been used in the acoustic discipline in order to handle large differences in absolute values of pressures and energies. With the use of a decibel scale, transmission loss (TL) computations become "add and subtract" operations rather than "multiple and divide" operations, thereby simplifying calculations. Additionally, linear values which can cover many orders of magnitude are represented in scales which may cover one or two orders of magnitude. A "dB" is ten times the logarithm to the base ten of the ratio of the measured intensity or energy to a reference intensity or energy. In air the customary intensity reference is 20 micropascals (20 µPa) and in water the customary intensity reference is 1 µPa. To convert from in-air dB to in-water dB, simply add 26 dB. Thus a reading of 100 dB re 20 µPa is 126 dB re 1 µPa. Where "re" means "referenced to:" The same relationship holds for energy flux density (EFD) decibels. If in-air EFD levels are given, add 26 dB to get in-water EFD levels. Further, in order to match intensity levels with the sensitivity of the human ear, weighting is given to the dB readings as a function of frequency. The most common is "A-weighting" and it is indicated as "dBA." If a letter after the dB is not given, then it is assumed it is an un-weighted sound pressure level; this is not always the case in literature, but it is in this report. Many noise measuring meters are designed to indicate noise levels in dBA (e.g., the "weighting" is built into the meter and should be indicated on the instrument). It is important to note what weighting is being used before comparing noise levels. Additionally it should be noted that the standard “A-weighting” is frequency dependent. In this analysis it was determined that the highest 1/3-octave band typically occurs for the sources at about 500 Hz. At this frequency the “A-weighting” is about 4 dB. This single value will be used conservatively throughout this report to change from “A-weighted” to unweighted values. For frequencies below 500 Hz, the weighting value increases (e.g., about 25 dB for 100 Hz) and for frequencies about 500 Hz the in-band energy level decreases. Therefore this assumption is conservative.

1.2 Established Injury and Harassment Criteria

The primary United States’ law applicable to protecting marine mammals is the Marine Mammal Protection Act (MMPA).

The MMPA, subject to limited exceptions, prohibits any person or vessel subject to the jurisdiction of the United States from “taking” marine mammals in the United States or on the high seas without authorization. “Taking” includes harm or harassment. Section 101(a)(5) of the MMPA directs the Secretary of Commerce to allow, upon request, the incidental (but not intentional) taking of marine mammals by U.S. citizens who engage in a specified activity (exclusive of commercial fishing) within a specified geographical region if certain findings are made and regulations are issued. Permission may be granted by the Secretary for the incidental take of marine mammals if the taking will: 1) have a negligible impact on the species or stock(s); and 2) not have an unmitigable adverse impact on the availability of the species or stock(s) for subsistence uses. Regulations must be issued setting forth the permissible methods of taking and the requirements for monitoring and reporting such taking.

The term “take” as defined in Section 3 (16 United States Code [USC] 1362) of the MMPA and its implementing regulations means “to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal.” The term “harassment” means any act of pursuit, torment, or annoyance that has the potential to:

- Injure a marine mammal or marine mammal stock in the wild (MMPA Level A harassment); or

- 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 (MMPA Level B harassment).

The MMPA was modified slightly by the National Defense Authorization Act (NDAA) of 2004, but for the purposes of this document, the specific criteria and calculation techniques utilized in the *U.S.S. Seawolf* and *U.S.S. Churchill* FEISs' (DoN 1998 and 2001) are replicated here.

In-Water Impulsive Source Criteria

The *U.S.S. Seawolf* and *U.S.S. Churchill* FEISs' (DoN 1998 and 2001) methodology for determining the potential for effects on marine mammals resulting from the use of explosives in water has been formally accepted in published Final Rules by NOAA Fisheries/National Marine Fisheries Service (NMFS). Currently, these criteria are based on the best science that is available from all in-water and terrestrial experiments and extrapolations. From these, the following dual criteria for harassment (MMPA Level B incidental takes) are established:

- The onset of Temporary Threshold Shift (TTS) is estimated to occur when the highest 1/3-octave band RL at an animal exceeds 182 dB re $(1\mu Pa)^2 \cdot s$ (EFD), or
- The onset of Temporary Threshold Shift (TTS) may occur when an animal is exposed to a 12 pounds per square inch (psi) or greater peak pressure.

For plane waves, EFD is the time integral of the squared pressure divided by the acoustic impedance of sea water. It is assumed the acoustic impedance is the same throughout the sound field. EFD has units of Joules per meter squared or pound force per square inch. In-water EFD levels are by convention expressed in "dB re $(1\mu Pa)^2 \cdot s$" (Urick, 1983), while in-air EFD levels use the reference "dB re $(20\mu Pa)^2 \cdot s$."

The dual Level B incidental harassment criteria will be identified as the "TTS-Energy" and "TTS-12 psi" criteria, respectively, hereafter. The "TTS-Energy" criterion applies to the received signals in the highest 1/3-octave band produced by a source. For mysticetes (i.e., baleen whales, see glossary), 1/3-octave bands above 10 Hz are considered, while for odontocetes (i.e., toothed whales/dolphins, see glossary) 1/3-octave bands above 100 Hz are used. The "TTS-12 psi" peak pressure criterion effectively uses the pressure from all frequencies. The maximum range (or radius) from the source where these TTS criteria are met defines the zone of influence (ZOI) for incidental harassment (Level B) for a single explosion.

TTS was accepted as the Level B (i.e., "harassment" criteria) for the *U.S.S. Seawolf* and *U.S.S. Churchill* FEISs because the actual explosion planned for those tests were a one time occurrence and effectively, the potential "startle" reaction from a single explosion was not considered a "behavior" harassment. TTS was identified and accepted as a better metric of Level B harassment in those documents. The applicability of a similar assumption and utilization of TTS for the Level B criteria for this document can be questioned since a typical CALFEX consists of many explosive events over a 3-4 hour period. However, the case can made that only a very few explosions can be heard in the waters off MMR and (as will be presented later in this paper) the RLs of these signals are 30 dB or more below the TTS criteria. Essentially, only a few explosions might be heard at relatively low levels; therefore, the use of TTS as the Level B criterion is reasonable.

The *U.S.S. Seawolf* and *U.S.S. Churchill* criteria also define dual-injury criteria (MMPA Level A injury) for marine mammals as follows:

- 50 percent Tympanic Membrane (TM) rupture.
- Onset of slight lung injury.

These dual Level A injury criteria will be identified as the "Injury-Energy" and "Injury-Positive Impulse" criteria, respectively, in this document.

The 50 percent TM criterion was based on experiments with terrestrial mammals, which had been exposed to detonations (in water). This recognizes that a "TM rupture *per se* is not necessarily a serious or life-threatening injury, but is a useful index of possible injury that is well correlated with measures of permanent hearing loss." The EFD associated with 50 percent TM rupture was established as "1.17 in-lb/in^2 (20.44 milli-joules/cm^2"). Note that in SI units this is equivalent to 204.4 J/m^2, or EFD level of approximately 205 dB re (1µPa)^2 • s, where specific impedance of water has been set equal to $\rho c = 1.5 \times 10^6$ kg • m^{-2} • s^{-1}.

The onset of slight lung injury for a small animal (e.g., a dolphin calf) has been calculated using the *U.S.S. Churchill* FEIS (DoN 2001) methodology and is indexed to 13 psi-ms for a 27 lb (12.2 kg) animal on the surface. This is the conservative case since the positive impulse needed to cause injury is proportional to animal mass and therefore larger animals require higher impulse to cause the onset of injury. The methodology used in the *U.S.S. Churchill* FEIS (DoN 2001) is usually referred to as the "Goertner modified positive impulse method" and two different time criteria are used to calculate the positive impulse at any range. The first is the time interval between the direct path arrival and the surface-reflected arrival from the explosion to the position of the animal. The other time interval is 20 percent of the lung volume resonance period for the animal's length/mass and it is calculated at the animal's depth. The lesser of these two time periods are used in the calculations as recommended by Goertner (1982).

It should be noted that all of these impulsive criteria are for a single explosion. Methodologies have been devised to extend these criteria to multiple explosives (DON, 2004 and Federal Register 22Apr2004). Effectively, those criteria which involve energy determine the size of their zone of influence by summing the energy from subsequent explosions.

<u>In-Water Coherent Source Criteria</u>

In-water coherent source criteria commonly in use today are based on studies which began to be published in 1997 and continue to this day. "Behavioral Responses and Temporary Shift in

Masked Hearing Threshold of Bottlenose Dolphins, *Tursiops truncatus*, to 1-second tones of 141 to 203 dB re 1 μPa" (Ridgway et al. 1997) is one of the first of a series of comprehensive studies of the effect of underwater acoustic noise on marine mammals. During this study, researchers observed behavioral modifications and temporary shifts in the hearing sensitivity of bottlenose dolphins exposed to 1-second tones at frequencies between 3 and 75 kHz. More recent work (Schlundt et al. 2000) extended the data to 400 Hz, included work with beluga whales, and used masking noise to create a consistent ambient noise environment. The conclusions of these studies are that temporary shifts in the hearing levels of odontocetes were observed at the average RLs of 195 dB.

A re-evaluation of the results in these studies has produced an as-yet unpublished (either in peer-reviewed scientific papers or as Regulator/NMFS-reviewed environmental compliance documents) estimate of 190 dB as a threshold for changes in behavior. Additionally, NOAA/NMFS is working to define and publish criteria for Level A and Level B harassment. However, those criteria are not yet available. Therefore, for the purpose of this analysis, the 190 dB change in behavior criteria will be assumed as an appropriate reference value.

Current thought is that total received energy may be a more appropriate metric for determining the RLs at which "Change in Behavior," "Temporary Threshold Shift (TTS)" and "Permanent Threshold Shift (PTS)" occur. By using a total received energy approach, both pulse-length and multiple received pulses are accounted for. For cetaceans (i.e., whales, dolphins and porpoises – see glossary), the selected levels for these metrics that were used in the impact analyses are as follows:

Change in Behavior (Level B):	190 dB re $(1\mu Pa)^2 \cdot s$
Temporary Threshold Shift:	195 dB re $(1\mu Pa)^2 \cdot s$
Permanent Threshold Shift (Level A):	215 dB re $(1\mu Pa)^2 \cdot s$

1.3 Planned Operations and Explosives Employment

The planned operations consist of both day and night CALFEXs. The ordnance employed for a typical day and a typical night exercise is shown in Table 1-1. In addition, during the day and night, several types of helicopters will be operating in and around the area.

Table 1-2 indicates the typical source levels for the ordnance, helicopter, and gunfire events that may occur. The source levels shown are in dB. It should be noted that each source has two different source levels depending on the medium that the sound will be traveling through. The values shown here are based on the empirical formulae that have been derived historically for explosions in air and in water. Since the acoustic impedance of soil is similar to that of water, the empirical formulae for water are also used for the ground paths. For the water and ground paths, the empirical formulae for ordnance detonations were identified by Arons (1949) and repeated in Richardson (1995). For the air paths, the procedure in ANSI standard S2.20 was used. The gunfire and helicopter source level in air were taken from U.S. Army website (CHPPM, 2004) and adjusted using spherical spreading to a reference distance of one meter from the muzzle of the gun for the gunfire values. The ground and water source level estimated for the gunfire and helicopters uses the in air value and assumes a 10 dB loss for the sound penetrating into the ground. This is similar to the critical angle issue of airborne sound penetrating into the ocean as discussed in Section 2.3. Finally, the 300 lb Demo Charge is assumed to be 300 lb of Ammonium Nitrate in a cratering charge configuration.

The analysis performed herein was for each noise event individually. Two or more noise events at the same time can add; however, for gun-firings and detonations, even if occurring at the same time, they will probably have different propagation paths and can be out of phase and not completely add. It should be understood that the possibility of explosive signals, which are only tens of milliseconds in duration, generated hundreds of feet apart, fired individually (at least seconds and potentially minutes apart) are very unlikely to have signals arrive at a common receiver that overlap in time. For the purpose of this analysis, it is assumed that a combination of different spatial and temporal source times/locations and the complexities of the multiple transmission paths will preclude this addition from occurring.

Table 1-1 Ordnance Employed in a Typical CALFEX

Item	Day	Night
Bangalore	2	1
155 mm HE	218	108
105 mm HE	71	50
Javelins	2	0
2.75 rockets	28	28
81 mm HE	29	20
AT-4 antitank	2	1
Claymore	5	4
C4 2 lbs	2	1
60 mm HE	22	15
Grenades	20	14
Smoke	7	5
fuses/cords	33	23
Small arms ammunition	18,000	12,500
60 mm inert	27	19
Inert TOW	1	1
40 mm inert	40	28

Table 1-2 Source Noise Level (dB)

Source Type	Estimated Source Level for Ground and Water Paths (dB re 20 micro Pa at 1 m)	Estimated Source Level for Air Paths (dB re 20 micro Pa at 1 m)
Ordnance Detonations Sources *		
300 lb Demo Charge	261.6	235.2
Bangalore	261.4	235.0
Cratering charge	257.8	231.9
Shape charge (40 lbs C4)	256.9	231.1
155 mm HE	256.0	230.3
105 mm HE	253.8	228.4
Shape charge (15 lbs C4)	253.8	228.3
M21 anti-tank mine	253.4	228.0
120 mm HE	252.0	226.8
Javelins	251.1	225.9
2.75 HE rockets	248.7	223.8
81 mm HE	248.5	223.7
SMAW	247.9	223.1
AT-anti-tank rockets	247.9	223.1
Claymore	246.9	222.2
C4, 1.25 lbs	246.2	221.6
60 mm HE	245.2	220.7
Grenades	243.5	219.2
Illumination rounds for 81 mm HE mortar	237.5	213.9
Illumination rounds for 105 mm HE mortar	237.5	213.9
Illumination rounds for 155 mm HE mortar	237.5	213.9
Smoke	234.3	211.1
81 mm inert	223.2	201.2
60 mm inert	223.2	201.2
40 mm inert	223.2	201.2
Fuses/cords	223.2	201.2
Ammo	223.2	201.2
Inert TOW missiles	223.2	201.2
Gun Fire Sources **		
155 mm howitzer	185.0	195.0
105 mm howitzer	184.0	194.0
120 mm mortar	178.0	188.0
81 mm mortar	173.0	183.0
60 mm mortar	173.0	183.0
small arms	154.0	164.0
Helicopter Sources ***		
CH-47D	104.0	114.0
UH-60A	102.0	112.0
OH-58D	98.0	108.0

Notes:
* SL approximated based on Arons (1949) and ANSI S2.20
** SL from Reference CHPPM, 2004 with corrections
*** SL from Reference CHPPM, 2004 with corrections

2.0 MODELING METHODOLOGY

Acoustic propagation models were used to predict the in-air and in-water noise levels for each type of ordnance and each aircraft. In general, these models utilize various approaches (i.e., solutions or approximate solutions of the wave equation) to estimate the effects of the transmission medium and boundaries on an acoustic signal transmitted at a source and "heard" at a receiver. Typical environmental effects include attenuation, reflection, refraction and result in modification of the signal as it propagates to the receivers.

For this effort, three source locations and five receiver sites were modeled. Table 2-1 lists these sites and pertinent details about them.

Table 2-1 Modeled Sites

Site	Description	Sources Used There	Elevation at site (ft)	Comments
Source Sites				
A	Objective Buffalo	Artillery/mortar firing point	240	Muzzle – 2 m (6.6 ft) above ground
B	½ way between Objective Deer and OB/OD area	Explosives impact point	350	Explosions occur at ground level
C	Approximately 2,000 ft south of N3 point, east of ridge	Helicopters	160	Helicopters modeled at 300 & 1,000 ft above the ground
Receiver Sites				
1	On beach, in State Park, 500 ft north of MMR	none	Sea level	Microphone 2 m above ground
2	Planned hydrophone location, about 1,000 ft offshore	none	Sea level	Microphone 2 m above and hydrophone 5 m below ocean surface
3	Planned hydrophone location, about 200 ft offshore	none	Sea level	Microphone 2 m above and hydrophone 5 m below ocean surface
4	Former N1 site	none	Sea level	Microphone 2 m above ground
5	Former N5 site	none	Sea level	Microphone 2 m above ground

As discussed in Section 1.2, the current in-water impulsive criteria consist primarily of instantaneous maximum of pressure and/or energy levels for a single explosion event, or the summation of the energy over multiple events. Therefore, the modeling approach used here will also derive values of comparable units so that the impact on in-water marine mammals (specifically, spinner dolphins) can be assessed. For helicopter operations, the instantaneous peak received pressure (i.e., the addition of energy from all frequencies produced) will be compared to the criteria for a nominal one second duration. This does not account for the addition of acoustic energy over time, but this can be corrected for by converting to energy and adding to the helicopter's source level at a rate of 10 times the Log of the duration of signal in seconds.

2.1 Airborne Transmission Modeling

The model used to estimate in-air acoustic propagation was the Navy Standard Comprehensive Acoustic System Simulation (CASS) / Gaussian Ray Bundle (GRAB) model (Keenan, 2000).

This model is a range dependent program that computes the TL associated with the potential propagation paths between a source and a receiver. Gaussian Beam models have been demonstrated to successfully model the complex atmospheric sound propagation (Gabillet, 1993). The underwater acoustic model identified here was modified to account for the differences between air and water propagation.

TL is the loss in intensity of sound as it travels from the position of the event to the position of the prediction point. TL in air is greatly affected by temperature, humidity, wind speed and direction, and most particularly by obstructions and vegetation. Consequently, the TL can have a large variance depending on the aforementioned parameters. Likewise, in water, TL is affected by temperature, salinity, pressure, wind speed, and surface roughness.

Due to the variability of these environmental parameters, it was necessary to examine them both seasonally and diurnally. The details of those investigations are provided in Section 3.1, but for the purposes of understanding the overall modeling it should be understood that conservative values (i.e., cases that result in relatively low TL and higher RL at the modeled sites) were utilized throughout the modeling. It should be noted that the typical CALFEX begins at daybreak and continues for about four hours, completing at about 10:00 AM, local time. Actual CALFEX timing (and its impact on acoustic parameters) was considered in this analysis as discussed below.

For the modeling reported on here, a single air radiosonde profile was selected for the numerous model runs. This profile was from the fall season (November) and was the only profile for any season, day or night, which exhibited a ducting or trapping of acoustic energy near the ground. All other profiles showed near surface warming which resulted in upward refracting of acoustic energy, and greatly reduced predicted levels at the modeled receiver sites. Effectively, for these other cases, any anthropogenic, near-surface noise rapidly refracts (bends) upward and propagates into the atmosphere with minimal energy returning to the ground at the receiver points.

Since the Navy Standard CASS / GRAB model is a range dependent model (i.e., it is able to incorporate the effects of new environmental data in the TL estimations from the source to the receiver), critical environmental data such as ground elevation and type of plants present were digitized on a grid with a resolution of approximately 200 yards (183 m).

2.2 Seismic (In-ground) Modeling

Detonation noise propagated via the ground to the water

Analysis was performed to determine if marine mammal harassment criteria were exceeded in the water adjacent to the training area due to seismic energy transferred from the detonations of high explosives, via the ground and coupled into the ocean. The energy transferred from a detonation will produce a shockwave in the soil and rock below the explosion. The energy in this shockwave while in the earth is called "seismic" energy. Unlike acoustic energy in air or water, both being transferred via a single wave mechanism, seismic energy is contained in two different wave mechanisms consisting of compressional waves (P-waves – see glossary) and shear waves (S-waves – see glossary). For the weathered surface layer on land (soil), the velocity of the P-waves are about 500 m/s in loose soil and about 2500 m/s in consolidated sands and sediment under the water, and about 4000 m/s in limestone (coral) and the volcanic rocks (primarily rhyodacite and Icelandite) that underlie both the soil and the water. In the bedrock, the ratio of the velocity of the P-wave to the S-wave varies between about 1.5 and 2.1. In the sea water, the velocity of sound is about 1500 m/s. The widely varying sound velocities in the layers of material through which the sound must travel create large directional changes in the sound waves. These paths can be predicted by computer models and the TL associated with each path can be estimated. With the TL estimated, and the source level known for each type of ordnance detonation, a prediction can be made for RL at any point in the ocean beyond the shoreline. Analogous to transfer of acoustic energy from the air to the water, a critical angle exists. If the angle of incidence of the sound wave is less than the critical angle, the wave reflects back into the underlying sediments. From a single detonation, the received noise at any position in the water will be divided into a series of low level pulses. This is due to the many acoustic paths through different lengths of different density material. To be conservative, the assumption is made these many paths are in phase and add in pressure. Since many arrivals will be out of phase, the actual pressure will be less than the calculated pressure.

As an example of the seismic transfer of energy from a detonation from land to sea, the maximum weight of 126 lbs of high explosive (300 Lb demolition charge) was considered at a detonation height of ground level. At the shoreline, very conservatively the predicted TL is 96.5 dB. This is the sound intensity lost in the transfer of the shockwave in air to soil and the transmission through the soil and bedrock between the detonation site and the shoreline and from the bedrock to the sediments and from the sediments to the water body. Note, the depth and density of the surface soil layer as well as the sediment and sand layer can vary greatly and can significantly change the TL estimate. However, the conservative estimates made here predict a minimum TL which should be expected, and variations in the sediment parameters would be expected to increase TL. If all the energy in the acoustic shockwave at the shoreline penetrates into the water (highly unlikely due to critical angle and signal phase considerations) the in-water noise level from the detonation will be no more than 161.7 dB re 20 µPa or 187.7 re 1 µPa and will most likely be below this worst case number. This is equivalent to about 0.352 psi, and thus far below the Level B harassment TTS-12 psi criterion for marine mammals. It should be noted that additional TL will occur as the sound travels through the water and this will further reduce the RLs present in the water. Therefore, any marine mammal beyond the shoreline will not experience any sound intensity exceeding the criterion. Since the largest explosive weight ordnance was considered, no detonations will exceed the marine mammal TTS-12 psi criterion anywhere in the water.

Similar analysis to the above paragraph shows any detonation of planned individual ordnance devices will not exceed the other marine mammal criteria for Level A or Level B. However, an additional analysis must be performed to examine the summation of energy criteria for multiple detonations. To start this analysis, it was assumed that marine mammals (specifically dolphins) could be present in the vicinity of MMR for up to approximately 2 hours (i.e., half of a typical

CALFEX) and accumulate acoustic energy during that time period. The following detonations were assumed to occur during that period: 1 300 lb demolition charge (NEW 126 lb); 3 shaped charges (NEW 29.7 lb ea.); 20 155mm howitzer projectiles (NEW 22.5 lb ea.); 100 105mm howitzer projectiles (NEW 11.7 lb ea.). For this sample calculation, the time frame of two hours was chosen as a nominal maximum time that a spinner dolphin might remain close (i.e., with 1,000 m) to the shoreline and thus available to receive the maximum energy from each of the detonations. Various animal stay times and ordnance expenditures could be used here, but this example is intended to illustrate a realistic nominal case. The total received EFD level across all frequencies from all detonations over the two hours will be 139.2 dB re $(20\mu Pa)^2 \cdot s$ (165.2 dB re $(1\mu Pa)^2 \cdot s$) for a representative animal that remained within 1,000 m of the shore. This level is conservatively derived with the assumption that all acoustic multipaths arrive at the animal in phase. This assumption is conservative because the multipaths will not all be in phase, and the actual sum of energy will be less. The Level A total received energy criterion (Injury-Energy) is 205 dB re $(1\mu Pa)^2 \cdot s$. Therefore, no marine mammal will receive energy that exceeds the Injury-Energy criterion.

The same scenario as above an analysis was conducted of the highest sum of energy in any 1/3 band energy for odontocetes and mysticetes. The highest sum of received energy flux density (EFD) level in any 1/3-octave from all detonations over the two hours is 127.2 dB re $(20\mu Pa)^2 \cdot s$ (153.2 dB re $(1\mu Pa)^2 \cdot s$) for the nominal animal. Again this conservatively assumes all multipaths are in phase. The Level B energy criteria (TTS--Energy) is 182 dB re $(1\mu Pa)^2 \cdot s$. Therefore, no marine mammal will receive energy that exceeds the TTS-Energy criteria.

2.3 Modeling of Airborne Transmission into the Ocean

Propagation of acoustic energy from air into water has been by examined by numerous studies which have attempted to predict this propagation in the presence of waves, water-entrained bubble plumes, biologics, etc. In the simplified case of a flat (i.e., waveless) ocean, the most important parameter controlling air to water transmission is the relative difference of the sound speeds of air and water (Urick, 1983 and Richardson 1995). Effectively, because the speed of sound in water is nearly five times that of sound in air, only sound waves striking the ocean at very steep angle can penetrate into the ocean. The angle that separates the sound that penetrates into the ocean from that which does not, is called the “critical angle.” Typically, this critical angle is about 11.5° from the vertical. This means that any sound striking the ocean from an angle greater than 11.5°, is almost entirely reflected off the oceans surface and back into the air. A very small portion of the energy may “effervesce” into the ocean, but this would only be a few percent of the total energy and it would be a greatly reduced level (i.e., 20-40 dB or more reduction in the level of the incident sound level).

It must be remembered that the above discussion is for an idealized calm, flat ocean. In the presence of waves, the normal vectors to the waves’ surfaces (i.e., the vertical line which points away from the wave for that particular point on the wave’s surface) vary over the surface of the wave and with the size and shape of the wave. This is analogous to the “glints” of sunlight seen on the ocean in the presence of waves.

For moderate sea states, typical in the vicinity of MMR (i.e., sea states from 0 to 3, with wave heights less than 1.25 m (4 ft) (Bowditch 1995)), it is conservatively estimated that only about 10% of the in-air sound enters the water (McCormick, 1972). This is effectively a 10 dB reduction of the acoustic signal as it penetrates into the ocean at angles greater that the critical angle with the flat ocean. At higher sea states (i.e., sea states from 4 or 5, with wave heights 1.25 – 4 m (4-13 ft)), perhaps 20% of the in-air sound enters the water (i.e., a 7 dB reduction of acoustic energy). For even higher sea states such as can occur with high gale or hurricane winds, crashing waves and entrained air bubble plumes effectively limit sound transmission into the water.

2.4 In-Water Modeling

For all of the modeled acoustic paths identified during this acoustic analysis, the in-water portions of the propagation consists of very short paths (i.e., much less than 1,000 m and typically on the order of 3-30 m (10-100 ft)). Therefore the in-water propagation is spherical in nature with little or no absorption because of the short ranges. The following equation is sufficient and appropriate to estimate TL for these short ranges:

$$TL = 20 * \text{Log}(R)$$

Where: TL = Transmission Loss in dB, and
R = range in meters

3.0 ENVIRONMENTAL AND SOURCE PARAMETERS

3.1 In-Air Parameters

The most critical environmental parameter in determining the atmospheric propagation is the speed of sound in the atmosphere for the MMR. The National Climatic Data Center (NCDC), a part of the National Oceanic and Atmospheric Administration (NOAA), maintains an archive of radiosonde data (NOAA, 2004) that includes all of the information required to calculate the sound speed in air as a function of altitude (i.e., altitude, temperature, dew point temperature, air pressure and wind speed and direction) for numerous site throughout the US.

In that database, the closest site in the Hawaiian Islands to MMR is the Lihue, Kauai site. Radiosonde data were extracted for Lihue for the following months as representative of the seasons in parentheses:

February 2004	(winter),
May 2004	(spring),
August 2003	(summer),
November 2003	(fall).

From each month, two typical and representative profiles (one for day and one for night) were identified and used in subsequent analyses. Figure 3-1 shows the selected sound speed profiles, while Figure 3-2 is a close up of the lowest 1,000 m (3,281 ft) of those profiles. These sound speeds were derived from the NCDC radiosonde data using the equations identified by Cramer (1993). In those figures, the solid line (i.e., without symbols) represent nighttime data (the 1200 in the legend is noon GMT or approximately 1 AM Hawaii time), while the curves with symbols are for daytime. All data start at an elevation of 36 m (118 ft) because this is the elevation of the Lihue site. For this modeling analysis, it was assumed the trend of sound speed continued linearly to sea level and the lowest altitude sound speed slope was therefore extrapolated to an elevation of zero.

In Figures 3-1 and 3-2, all of the sound speeds, except for the November night data, decrease as altitude increases. This would cause acoustic energy to refract upwards. Conservatively, the November night sound speed profile was used in all subsequent modeling since it would provide the most acoustic energy arriving at the receiving sites. Combinations of wind, turbulence, and

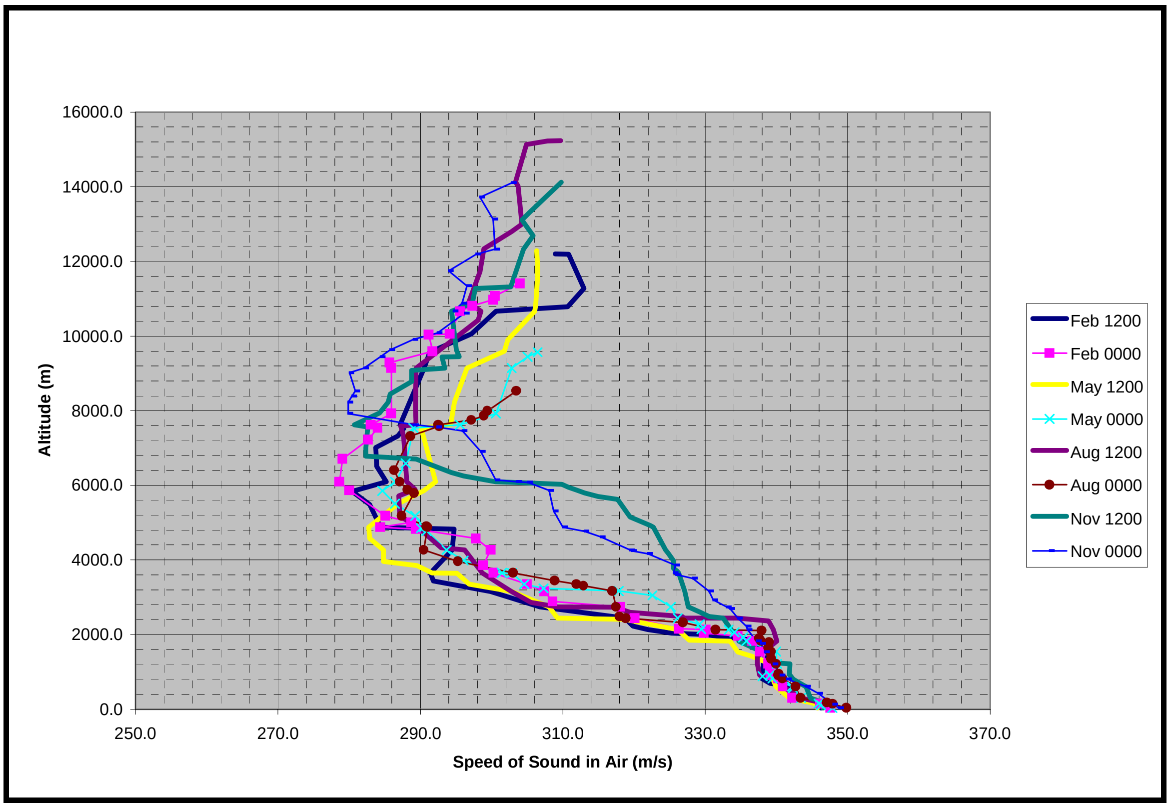

Figure 3-1 Sound Speed in Air for Lihue Site

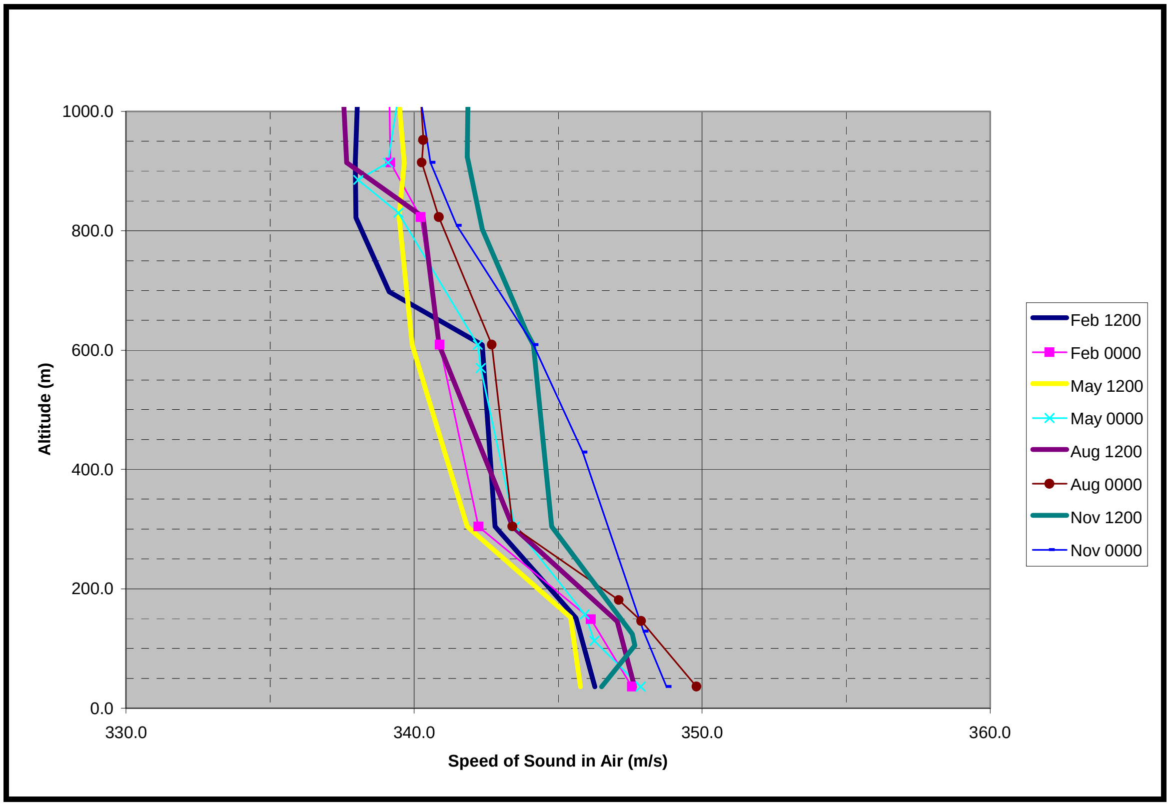

Figure 3-2 Enlargement of Sound Speed in Air for Lihue Site

density differences and other scattering mechanisms in the air could allow acoustic energy in these other profiles to reach the receiver sites, but they would be expected to have been reduced by 5-10 dB or more from the November night propagation which allows energy to be trapped near the ground.

It should be noted that although these radiosondes are from the Lihue site, they appear to be fairly representative of the MMR. Specifically, they were compared to the data available from two Makua Ridge Remote Autonomous Weather Stations (RAWS) and temperatures, humidities, and wind parameters agreed well. The RAWS stations are run by NOAA and routinely record and provide data to NOAA (NOAA, 2004b). The Makua Ridge RAWS sites are on Bureau of Land Management land, approximately 5 nm inland and above the MMR. Figure 3-3 provides a sample of the temperature of data for early July 2004.

The radiosondes also provided wind data for the Lihue site. Figures 3-4 and 3-5, respectively, show the wind speed and direction by season. Note that there was little difference diurnally so only one curve is provided per season. The conclusion drawn from these figures is that throughout the year the predominant near-ground winds are from the northeast to east at speeds typically 15 knots or less. For the MMR, this means that if a wind is present, typically it will come from inland, blow down the valley and out to sea.

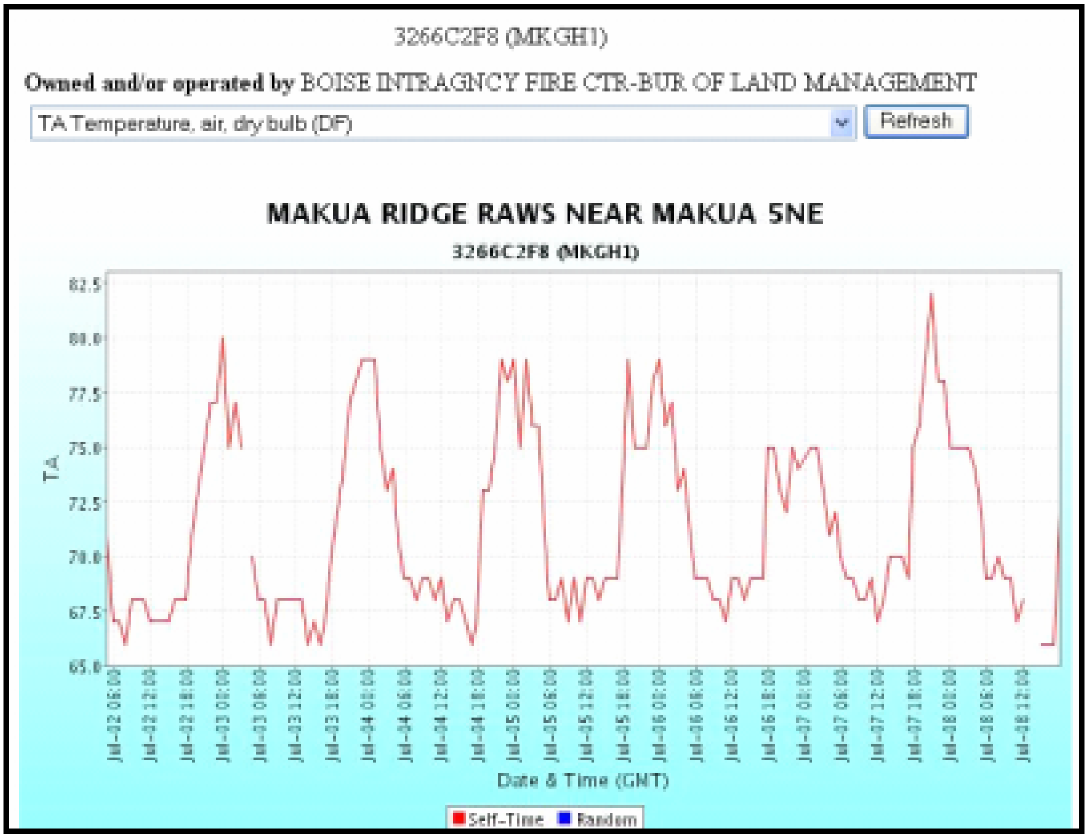

Figure 3-3 Makua Ridge RAWS Site Temperatures for July 2004

Acoustically this means that sites downwind from the sources will have enhanced propagation (i.e., less loss) and therefore higher received signals. Therefore the N1 and microphone receiver site will have increased RLs, while the state park site north of the MMR and the N5 site will have minimum impact from the wind.

The final in-air environmental parameter that needs to be addressed is the plant and tree ground cover for the area. As mentioned in Section 2.1, the MMR was subdivided using a grid of 200 m (183 yd) by 200 m increments and the ground cover was digitized. The baseline for identifying ground cover was the latest US Geologic Survey Quadrangle map for that area. For the modeled area four types of ground cover were identified: tree/forest, grass, sand, and water. The ground attenuation for the grass, sand, and water categories was conservatively assumed to be zero. The excess attenuation from the forested areas was estimated at 100 dB/kyd or 3.3 dB/100 ft. This appears to be a conservative value since the make-up of the forested areas is undefined and this value is approximately half that reported by Aylor (1971) for hemlock, corn, brush and pine over most frequencies from 100 – 10,000 Hz.

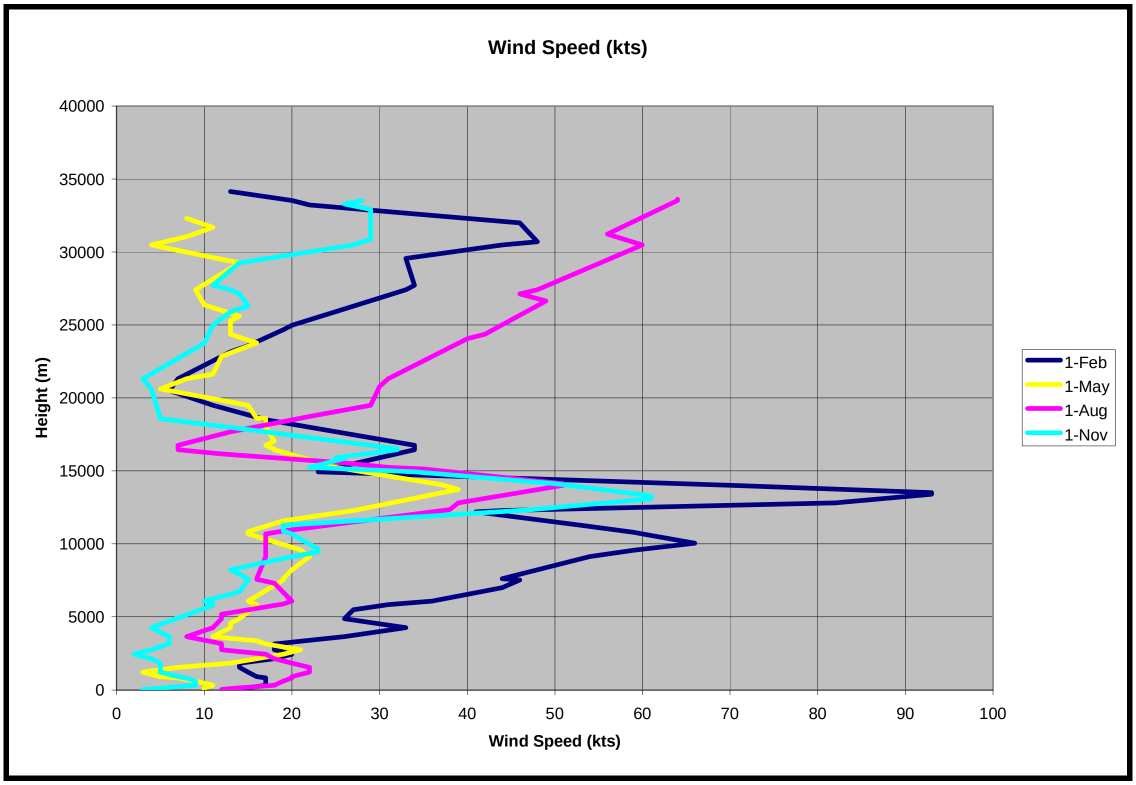

Figure 3-4 Wind Speed (kts) for Lihue Site

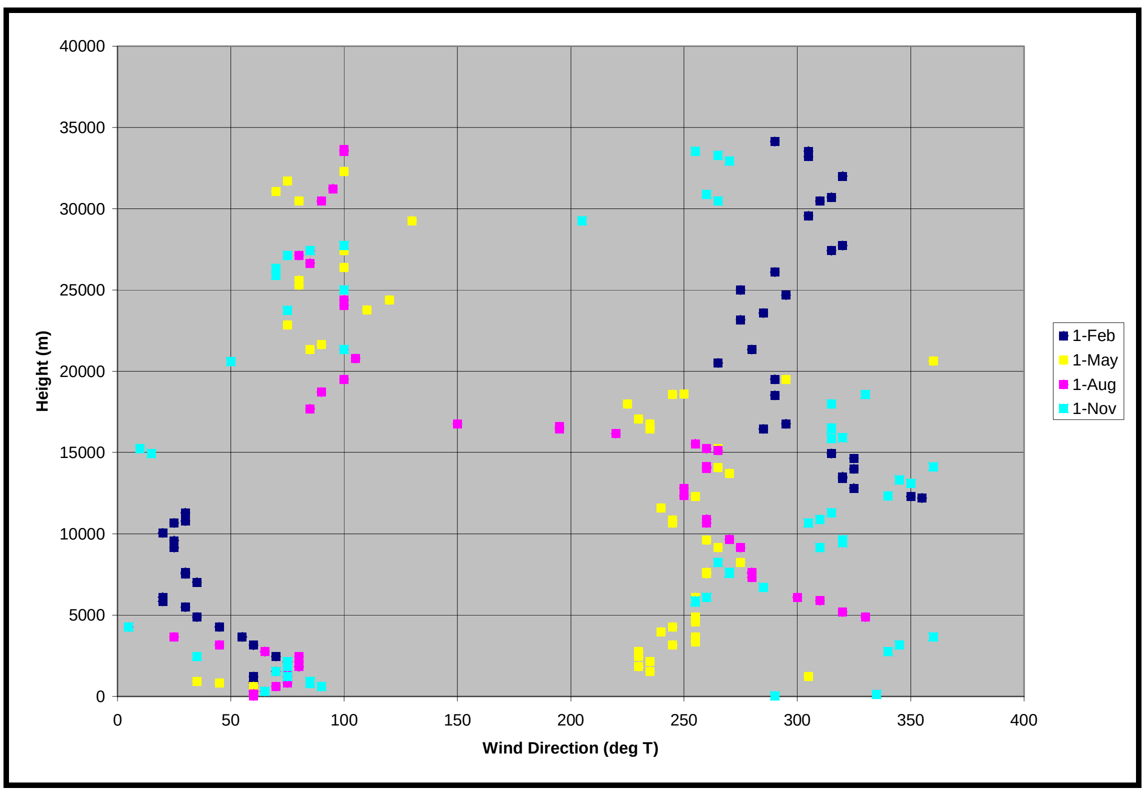

Figure 3-5 Wind Direction (°T) for Lihue Site

3.2 Seismic Parameters

At MMR, seismic propagation occurs in the following materials and at the listed speeds of sound used in this analysis:

Speed of sound in loose soil:	500 m/s
Speed of sound in sedimentary deposits:	2500 m/s
Speed of sound in rhyodacite, Icelandite and limestone:	4000 m/s

Published geologic maps (Landenheim, 2004) were used in the estimations of geologic structure and composition.

3.3 In-Water Parameters

As explained is Section 2.4, simple spherical spreading without absorption was assumed for in-water modeling, therefore no in-water parameters were required.

3.4 Helicopter Noise Parameters

The noise received from a helicopter in the near field and far field is primarily due to phenomena associated with the main rotor and the tail rotor and interactions between the two. Engine noise is of a much lower magnitude and can be considered a second order effect. Figure 3-6 is a representation of the mechanisms that produce noise from an operating helicopter and their relative magnitude and spectrum.

The main rotor produces primarily low frequency noise and in some operating regimes low and mid frequency noise modulated at the blade passage frequency. The low frequency noise consists of loading noise consisting of a fundamental and 20 to 30 harmonics and broadband turbulence noise. The magnitude and frequencies of each are a function of lift and rotational speed.

In descents, Blade Vortex Interaction (BVI) noise can dominate the resultant noise field and can be particularly annoying because this mechanism is typically produced as the helicopter prepares to land and therefore is at low altitude and often near persons and animals on the ground. BVI is an impulsive sound generated when a rotating blade's aerodynamic loading rapidly fluctuates due to interaction with vortices shed by the blade tip.

When a helicopter is transiting at high speeds, a phenomenon called High Speed Impulsive (HSI) noise can be generated that may significantly increase the magnitude and frequency of the main rotor blade noise. HSI noise is created at high helicopter airspeeds and propagates as impulsive wave fronts from each blade that can dominate the acoustic far field.

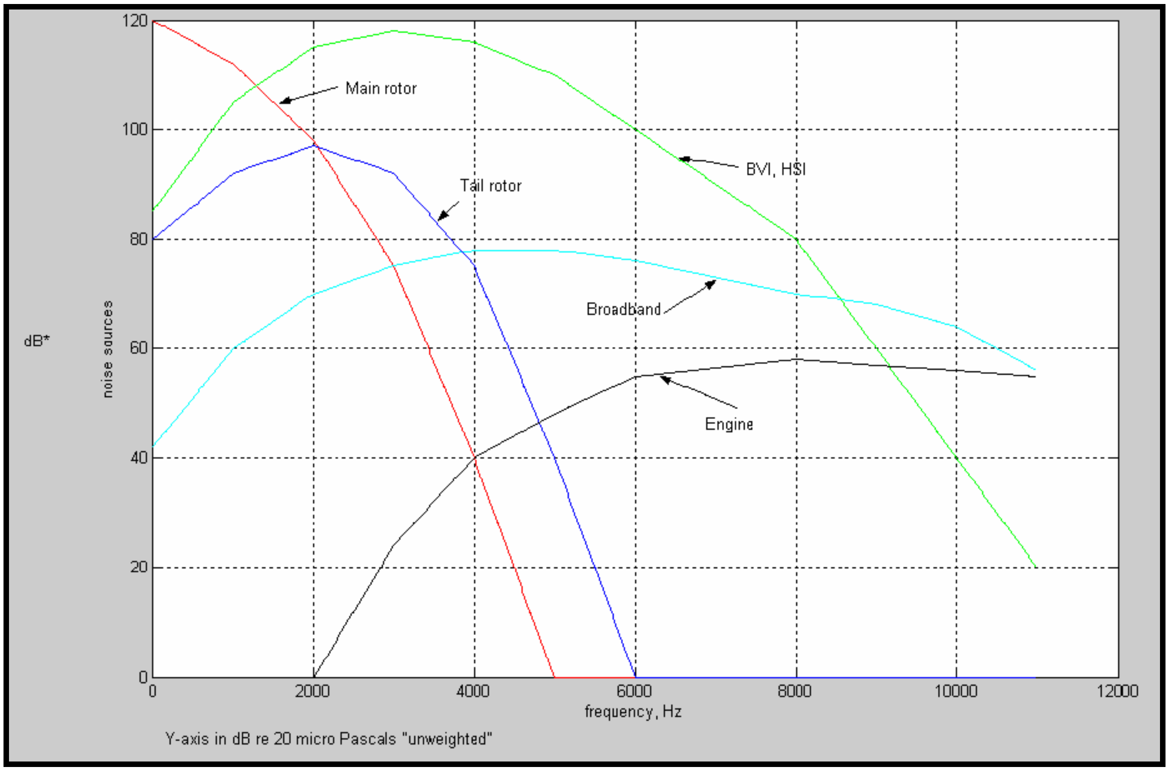

Figure 3-6 Primary Helicopter Noise Mechanisms

Each main rotor noise mechanism has a distinct directivity pattern. The basic lift or loading noise is directed down in a 30 - 40 degree cone, and the broadband noise is more in the disc plane while the HSI and BVI noise occur on the advancing blade side of the helicopter. HSI noise propagates most strongly forward in the plane of the rotor disc and BVI noise is strongest forward and down.

Tail rotor noise is often complicated by interaction with airflow over aircraft structures as well as interaction with the hub and blades of the main rotor. Similar to main rotor noise the tail rotor produces a fundamental frequency and a set of harmonics as well as broadband noise. Typically the amplitude of the noise from the tail rotor is reduced relative to the main rotor but the frequency is elevated and therefore more matched to the human hearing spectrum.

The modulated noise from a helicopter, known as "blade slap," attracts attention, much as a flashing light attracts more attention than a steady light, and therefore is more annoying to human observers than a steady noise at the same magnitude and in the same frequency band. By reducing the forward speed to 10 - 20 % below the rated max range cruise speed, such as whenever approaching the beach or populated areas, the pilot can significantly reduce the severity of this noise effect.

The noise footprint of a helicopter is a ground contour of equal sound levels. The approximate footprints for three types of Army helicopters operating at 300 foot altitude and at max range cruise airspeed is represented in Figure 3-7. In this representation the assumption is made that the wind speed is near zero. In windy conditions the footprint will be distorted with greater relative sound present downwind. The equal noise contours shown are for 50 dBA. These quantities are approximate for one set of operating conditions and can change significantly at other operating parameters.

It is important to note that the source level produced by a helicopter is largely dependent on the operating conditions of the craft. The pilot can control a number of parameters such as airspeed, altitude, flight path, disc loading, etc. to minimize annoyance to people and animals on the ground or in the water.

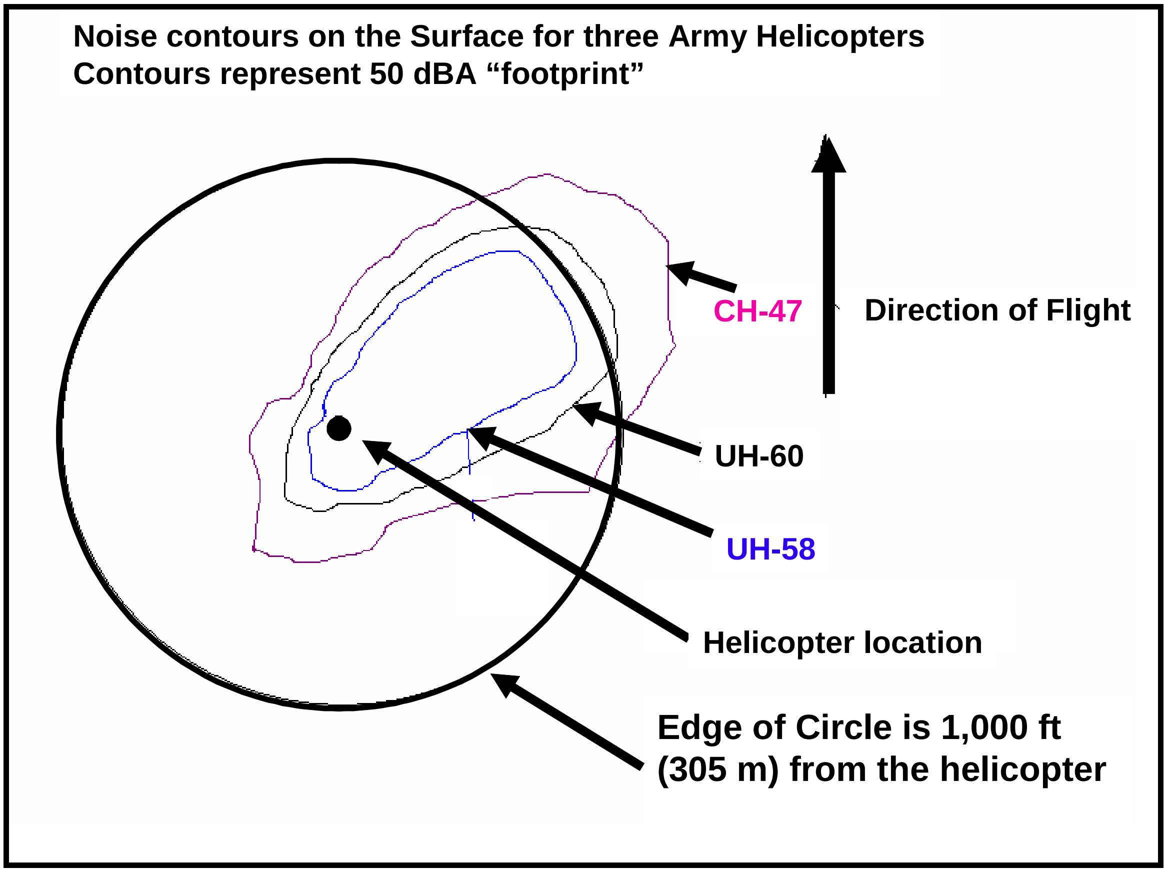

Figure 3-7 Helicopter Noise Footprint 300 ft Altitude, Max Range Cruise Speed

4.0 RESULTS

The results from the atmospheric propagation model include ray plots and TL plots for each source/receiver combination. Two samples of ray plots are provided for the source at the explosives impact site and receiver sites #1 and 3 (the state park site and the near-shore microphone site). These examples are Figures 4-1 and 4-2, respectively. In both figures the up-ward refracting rays are very obvious, but the rays trapped near the ground are only visible in Figure 4-2 because reflections from the hills in Figure 4-1 quickly send the acoustic energy into the atmosphere.

Figure 4-3 shows a representative TL curve for the case of a source at source site B (the explosive impact area) and received at receiver site #4 (the former N1 site). In this figure the discontinuity at a range of 1.7 nm is caused by the limit of the digitally modeled area. The TL curves for three different elevations are shown: sea level, 100 and 400 ft above sea level. Note that at a range of approximately 0.55 nm the TL curve for the 100 ft elevation receiver begins. This is due to the fact that at distances closer to the source than 0.55 nm, the model “sees” the receiver as underground and therefore doesn’t compute any ray path solutions. Finally, this figure shows the TL for the completely airborne transmission path between the source and the receiver at sea level. The TL value at 1.1 nm from the receiver site #4 is 152 dB. This TL value and those for each source/receiver combination are provided in Table 4-1.

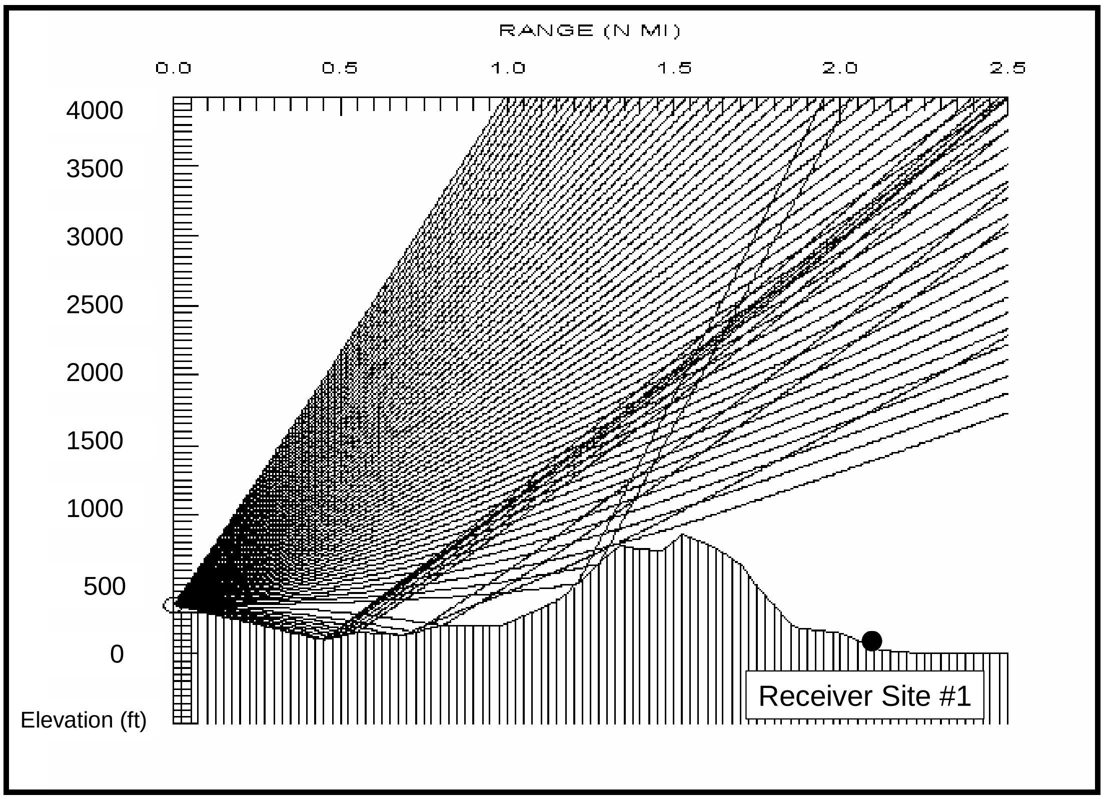

Figure 4-1 Ray Plot from the Explosives Impact Site to Receiver Site #1 (State Park Site)

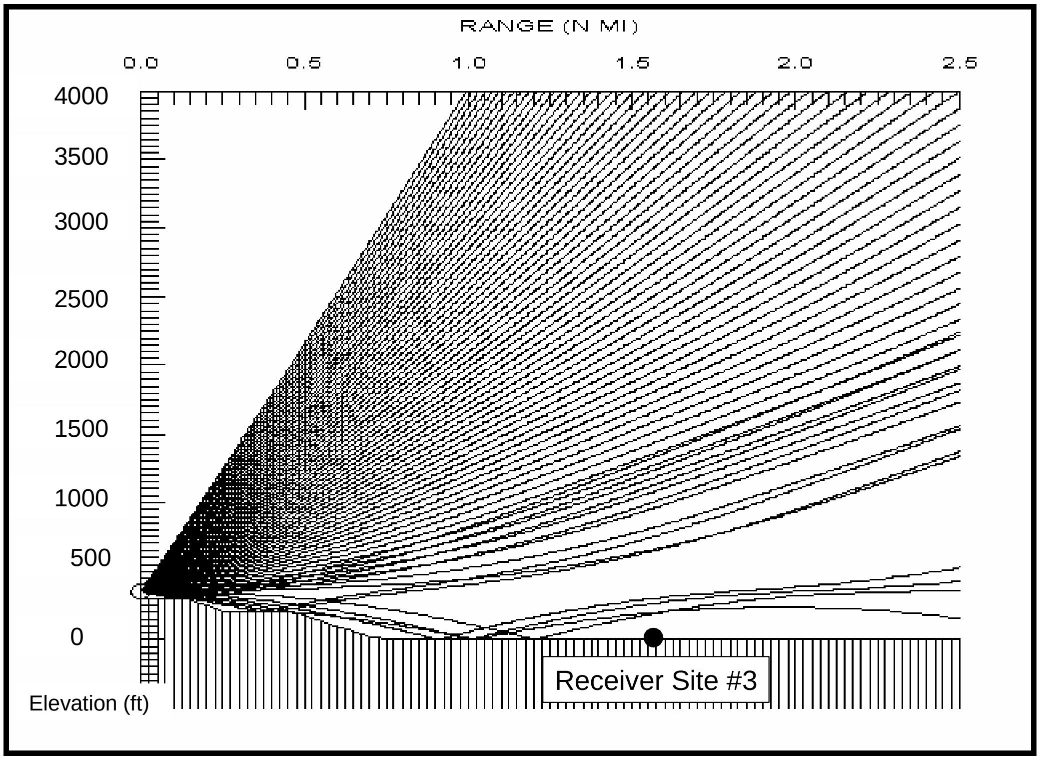

Figure 4-2 Ray Plot from the Explosives Impact Site to Receiver Site #3 (Near-shore microphone)

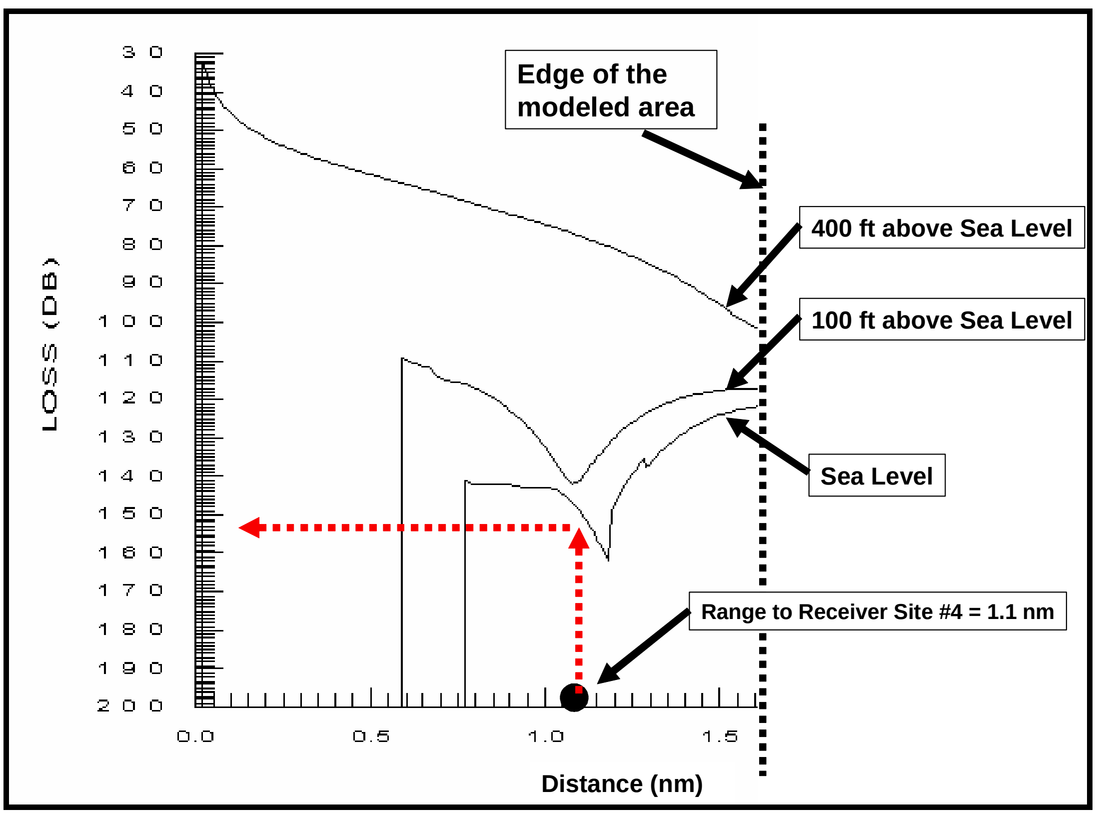

Figure 4-3 TL Plot from Source Site B to Receiver Site #4

Table 4-2 provides the resulting RLs at each receiver site for each of the sources identified in Table 1-2. The sources have been broken up by type (i.e., explosive ordnance, the gunnery firing noise, and helicopters at 300 and 1,00 ft), and arrange in increasing source level order (i.e., the stronger source in any type is listed higher on the table). The values in this table were derived by convolving the SLs from Table 1-2 with the TL from Table 4-1 and then correcting for conversions. In all calculations made for this report, the dominant in-water TL case (i.e., the least TL path case) has been used. Two examples are provided below for clarity.

For the 300 lb demolition charge the RL at Receiver Site #2, both air and water levels, were determined as follows:

In Air Case:	235.0	SL in dB re 20 μPa – from Table 1-2
	-158.0	TL in dB – from Table 4-1 (B to #2)
	77.0 dB re 20 μPa	
In Water Case:	261.4	SL in dB re 20 μPa – from Table 1-2
	-153.0	TL in dB – from Table 4-1 (B to #2)
	+ 26.0	to convert to in-water units – dB re 1 μPa
	134.4 dB re 1 μPa	

For the CH-47D helicopter at 300 ft, at source site "C," the RL at Receiver Site #2, both air and water levels, were determined as follows

In Air Case:	114.0	SL in dB re 20 μPa – from Table 1-2
	- 80.0	TL in dB – from Table 4-1 (Helo at 300 ft - #2)
	24.0 dB re 20 μPa	
In Water Case:	104.0	SL in dB re 20 μPa – from Table 1-2
	- 75.0	TL in dB – from Table 4-1 (Helo at 300 ft - #2)
	+ 26.0	to convert to in-water units – dB re 1 μPa
	55.0 dB re 1 μPa	

It should be noted at this point that in some cases the above method of calculation will result in a RL that is below the ambient noise level. For simplicity, the overall average ambient noise level for this document are assumed to be 55 dB re 20 μPa for the in-air case and 55 dB re 1 μPa for the in-water case. In Table 4-2, when the MMR signal is below these ambient noise level estimates a value of "Amb." is entered on the table.

As can be seen in Table 4-2, all RL values for all of the in-water RLs for the explosive sources are significantly below even the MMPA Level B, TTS and Level A criteria in Section 1.2, which is equivalent to about 218 dB re 1 μPa. Additionally, many of the less powerful sources are below ambient noise level or near it and probably cannot be heard *in situ*.

Table 4-1 Transmission Loss for Source / Receiver Combinations

Source	Receiver	Medium Receiver is in	Transmission Loss (dB)		
			Air Path	Seismic Path	Dominant Path
A	**1**	air	>180	N/A	>180
	2	air	155	N/A	155
	2	water	191	143	143
	3	air	160	N/A	160
	3	water	196	135	135
	4	air	145	N/A	145
	5	air	170	N/A	170
B	**1**	air	>185	N/A	>185
	2	air	158	N/A	158
	2	water	194	153	153
	3	air	135	N/A	135
	3	water	161	145	145
	4	air	145	N/A	152
	5	air	>180	N/A	>180
Helicopter @ 300 ft @ site C	**1**	air	80	N/A	80
	2	air	60	N/A	60
	2	water	75	N/A	75
	3	air	58	N/A	58
	3	water	73	N/A	73
	4	air	56	N/A	56
	5	air	75	N/A	75
Helicopter @ 1,000 ft @ site C	**1**	air	81	N/A	81
	2	air	62	N/A	62
	2	water	77	N/A	73
	3	air	61	N/A	61
	3	water	76	N/A	76
	4	air	59	N/A	59
	5	air	78	N/A	78
Helicopter @ 300 ft Over flight of Receiver sites	**1**	air	39	N/A	39
	2	air	39	N/A	39
	2	water	54	N/A	54
	3	air	39	N/A	39
	3	water	54	N/A	54
	4	air	39	N/A	39
	5	air	39	N/A	39
Helicopter @ 1,000 ft Over flight of Receiver sites	**1**	air	50	N/A	50
	2	air	50	N/A	50
	2	water	65	N/A	65
	3	air	50	N/A	50
	3	water	65	N/A	65
	4	air	50	N/A	50
	5	air	50	N/A	50

Notes:
1. "N/A" indicates that this propagation path was not calculated and is negligible
2. ">" indicates that this is the minimum TL and that actual TL the signal encounters is higher

Table 4-2 Estimated Received Levels

Source Type	Received Levels						
	In-Air Receivers *					In-Water Receivers**	
	Site #1	Site #2	Site #3	Site #4	Site #5	Site #2	Site #3
Ordnance Detonations Sources							
300 lb Demolition Charge	Amb.	77.2	100.2	90.2	55.2	134.6	142.6
Bangalore	Amb.	77.0	100.0	90.0	55.0	134.4	142.4
Cratering charge	Amb.	73.9	96.9	86.9	Amb.	130.8	138.8
Shape charge (40 lbs C4)	Amb.	73.1	96.1	86.1	Amb.	129.9	137.9
155 mm HE	Amb.	72.3	95.3	85.3	Amb.	129.0	137.0
105 mm HE	Amb.	70.4	93.4	83.4	Amb.	126.8	134.8
Shape charge (15 lbs C4)	Amb.	70.3	93.3	83.3	Amb.	126.8	134.8
M21 anti-tank mine	Amb.	70.0	93.0	83.0	Amb.	126.4	134.4
120 mm HE	Amb.	68.8	91.8	81.8	Amb.	125.0	133.0
Javelins	Amb.	67.9	90.9	80.9	Amb.	124.1	132.1
2.75 HE rockets	Amb.	65.8	88.8	78.8	Amb.	121.7	129.7
81 mm HE	Amb.	65.7	88.7	78.7	Amb.	121.5	129.5
SMAW	Amb.	65.1	88.1	78.1	Amb.	120.9	128.9
AT-anti-tank rockets	Amb.	65.1	88.1	78.1	Amb.	120.9	128.9
Claymore	Amb.	64.2	87.2	77.2	Amb.	119.9	127.9
C4, 1.25 lbs	Amb.	63.6	86.6	76.6	Amb.	119.2	127.2
60 mm HE	Amb.	62.7	85.7	75.7	Amb.	118.2	126.2
Grenades	Amb.	61.2	84.2	74.2	Amb.	116.5	124.5
Gun Fire Sources							
Illumination rounds for 105 mm HE mortar	Amb.	58.9	Amb.	68.9	Amb.	120.5	128.5
Illumination rounds for 155 mm HE mortar	Amb.	58.9	Amb.	68.9	Amb.	120.5	128.5
Smoke	Amb.	56.1	Amb.	66.1	Amb.	117.3	125.3
81 mm inert	Amb.	Amb.	Amb.	56.2	Amb.	106.2	114.2
60 mm inert	Amb.	Amb.	Amb.	56.2	Amb.	106.2	114.2
40 mm inert	Amb.	Amb.	Amb.	56.2	Amb.	106.2	114.2
Fuses/cords	Amb.	Amb.	Amb.	56.2	Amb.	106.2	114.2
Ammo	Amb.	Amb.	Amb.	56.2	Amb.	106.2	114.2
Inert TOW missiles	Amb.	Amb.	Amb.	56.2	Amb.	106.2	114.2
Gun Fire Sources **	Amb.	Amb.	Amb.	Amb.	Amb.	Amb.	Amb.
155 mm howitzer	Amb.	Amb.	Amb.	Amb.	Amb.	68.0	76.0
105 mm howitzer	Amb.	Amb.	Amb.	Amb.	Amb.	67.0	75.0
120 mm mortar	Amb.	Amb.	Amb.	Amb.	Amb.	61.0	69.0
81 mm mortar	Amb.	Amb.	Amb.	Amb.	Amb.	56.0	64.0
60 mm mortar	Amb.	Amb.	Amb.	Amb.	Amb.	56.0	64.0
small arms	Amb.	Amb.	Amb.	Amb.	Amb.	Amb.	Amb.
Helicopter Sources at 300 ft, at Source Site C							
CH-47D	Amb.	Amb.	56.0	58.0	Amb.	55.0	57.0
UH-60A	Amb.	Amb.	Amb.	56.0	Amb.	Amb.	55.0
OH-58D	Amb.	Amb.	Amb.	Amb.	Amb.	Amb.	Amb.
Helicopter Sources at 1,000 ft, at Source Site C							
CH-47D	Amb.	Amb.	Amb.	55.0	Amb.	Amb.	Amb.
UH-60A	Amb.	Amb.	Amb.	Amb.	Amb.	Amb.	Amb.
OH-58D	Amb.	Amb.	Amb.	Amb.	Amb.	Amb.	Amb.
Helicopter Sources at 300 ft, overflying the Receiver Site							
CH-47D	75.0	75.0	75.0	75.0	75.0	76.0	76.0
UH-60A	73.0	73.0	73.0	73.0	73.0	88.0	88.0
OH-58D	69.0	69.0	69.0	69.0	69.0	84.0	84.0
Helicopter Sources at 1,000 ft, overflying the Receiver Site							
CH-47D	64.0	64.0	64.0	64.0	64.0	65.0	65.0
UH-60A	62.0	62.0	62.0	62.0	62.0	77.0	77.0
OH-58D	58.0	58.0	58.0	58.0	58.0	73.0	73.0

Notes: * RL unit is dB re 20 µPa

** RL unit is dB re 1 µPa

The estimates of Ambient Noise Levels are 55 dB re 20 µPa in-air and 55 dB re 1 µPa in-water

Similarly for the helicopter sample, the RL are far below the 190 dB re $(1\mu Pa)^2 \cdot s$ coherent source Level B criteria and most are below the ambient noise levels. Even if the helicopter hovered in place for 30 minutes (1800 s) the total energy source level would only increase by 32.6 db (i.e., 10 *Log(1800)) and the maximum in-water RL would still only be 120.6 dB re $(1\mu Pa)^2 \cdot s$ at most, which are still far below the Level B harassment criteria.

Finally, it should be remembered that an easterly wind could possible increase RLs at receive sites #2, 3 and 4 by as much as 10-15 dB if conditions are right. However, even with this possible increase in in-water RLs, the highest in-water RLs would still only be 152.6 dB re 1 μPa, and the criteria would still not be exceeded.

5.0 CONCLUSIONS

The variability of the modeled/predicted RLs at the receiver sites are directly dependent on the modeled TL (i.e., the variability of the source levels is minimal). In conducting this analysis, the best available scientific, environmental, geologic, and meteorological data were obtained and used to calculate the TLs and subsequently to predict the RLs at the five receiver sites. Additionally, throughout this analysis, conservative assumptions were made. Therefore, the results presented here do not represent the full range of TL, which could occur, but an estimate of the typical nominal minimum TL (and therefore nominal maximum RLs) that can be expected for most days throughout the year. The results are not a “worst case” result, because there could be cases with stronger near-ground cooling or wind conditions which could increase the RLs, but days with these conditions would be infrequent and only represent an estimated 10-15 dB higher RL. Similarly, environmental conditions could greatly increase the TL, and effectively make the noise from the modeled sources indistinguishable from ambient noise. Therefore, great care will need to be exercised when comparing these results with *in situ* measurements. As a minimum, adequate environmental measurements (including radiosondes, sea state/wave height, wind speed, and direction, air and water ambient noise levels, etc) will need to be obtained in order to make comparisons to the modeled results presented here.

For in-air receivers, the dominant path was always the airborne propagation; while for in-water receivers, the dominant path was the seismic path. For the in-water receivers, the TL for airborne path was 20 to 50 dB more loss than the seismic path.

The results in Section 4 show the reader the estimated nominal, but conservative RLs for the modeled sites. These results for the individual sources show that the criteria for Level A or Level B harassment of marine mammals were never approached by the RLs at the in-water hydrophone or at any of the receiver sites. In fact, they were nominally 40 dB or more below even Level B thresholds and many were less than ambient noise level estimates for the MMR area. Additionally, planned helicopter operations resulted in RLs at the in-water receivers that were at worst only slightly higher than ambient noise levels. Therefore, it is highly unlikely that marine mammals potentially present offshore of MMR (i.e., in the vicinity of the modeled in-water receivers) would be impacted by a single or multiple CALFEXs or by individual high-explosive weapons at the MMR.

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APPENDIX A

GLOSSARY OF TERMS

GLOSSARY

Acoustics: The scientific study of sound, especially of its generation, transmission, and reception.

Ambient noise: The typical or persistent environmental background noise present in the ocean.

Anthropogenic noise: Noise related to or produced by human activities.

Baleen: The filtering plates that hang from the upper jaw of baleen whales.

Baleen whales: The filter-feeding whales, also known as mysticetes.

Cetacean: Of or belonging to the order Cetacea, which includes aquatic mammals with anterior flippers, no posterior limbs, and a dorsal fin; such as whales, dolphins and porpoise.

Compression wave (or "P-wave"): is a wave in which the restoring force is provided by compression in the material through which the wave travels. P-waves are the mechanism that transfers sound through liquids and gasses and is one of the two mechanisms for the transfer of sound in solids.

Decibel (dB): A unit used to express the relative difference in power, usually between acoustic or electrical signals, equal to ten times the common logarithm of the ratio of the two levels.

Endangered species: Defined in 16 U.S.C. 1532 as any species that is in danger of extinction throughout all or a significant portion of its range (other than a species of Class Insecta designated as a pest). Federally endangered species are listed in 50 CFR 17.11 and 17.12.

Harassment: Under the Marine Mammal Protection Act, any act of pursuit, torment, or annoyance that has the potential to:

- Injure a marine mammal or marine mammal stock in the wild; or
- 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.

Hertz (Hz): The unit of measure of frequency in cycles per second. 1,000 Hz is usually referred to as 1 kiloHertz (kHz).

Impedance (acoustic): The product of density and sound speed.

Mysticete: Any of several whales having symmetrical skulls, paired blow holes, and plates of whale bone (baleen plates) instead of teeth of the suborder Mysticeti. Filter-feeding whales, also referred to as baleen whales.

Odontocete: Any of the toothed whales (without baleen plates) having a single blow hole and asymmetric skull of the suborder Odontoceti, such as orcas, dolphins, and porpoises.

Otariid: One of three families of Pinnipedia having small but well formed ears (known as "eared" seals) including eared seals, sea lions, and fur seals.

Permanent threshold shift (PTS): The deterioration of hearing due to prolonged or repeated exposure sounds which accelerate the normal process of gradual hearing loss (Kryter, 1985), and the permanent hearing damage due to brief exposure to extremely high sound levels (Richardson et al., 1995b)

Pinniped: Of or belonging to the Pinnipedia, an order of aquatic mammals that include seals, sea lions, walruses and similar animals having fin-like flippers for locomotion. They are carnivorous and "haul out" on shore to have their pups.

Received level (RL): The level of sound that arrives at the receiver, or listening device (hydrophone). It is measured in decibels referenced to 1 micropascal root-mean-square (rms). Put simply, the received level is the source level minus the TLs from the sound traveling through the water.

Reflection: Process by which a traveling wave is deflected by a boundary between two media. Angle of reflection equals angle of incidence. (Richardson et al, 1995b)

Refraction: Bending of a sound wave passing through a boundary between two media; may also occur when physical properties of a single medium change along the propagation path (Richardson et al., 1995b).

Salinity: A measure of the quantity of dissolved salts in seawater. It is formally defined as the total amount of dissolved solids in seawater in parts per thousand (‰) by weight when all the carbonate has been converted to oxide, the bromide and iodide to chloride, and all organic matter is completely oxidized.

Shear Wave (or “s-wave”): is a wave in an elastic material in which the restoring force is provided by shear in the material through which the wave travels. Shear waves only propagate in solids.

SONAR: An acronym for SOund NAvigation and Ranging. It includes any system that uses underwater sound, or acoustics, for observations and communications. There are two broad types of sonar:

- **Passive sonar** detects the sound created by an object (source) in the water. This is a one-way transmission of sound waves traveling through the water from the source to the receiver; and

- **Active sonar** detects objects by creating a sound pulse, or ping, that transmits through the water and reflects off the target, returning in the form of an echo. This is a two-way transmission (source to reflector to receiver) and is a form of echolocation.

Sound pressure level (SPL): Twenty times the logarithm to the base 10 of the ratio of the pressure to the reference pressure, in decibels at a specific point. The reference pressure shall be explicitly stated. SPL is usually measured in decibels referenced to 1 micropascal (rms).

Sound speed: Sound speed is the velocity that sound waves travel through a medium. Sound speed through seawater is approximately 1,500 meters per second (4,920 feet per second). It varies with water temperature, salinity, and depth (pressure). Sound speed increases with increases in temperature and pressure (depth), and to a lesser extent with increase in salinity. This change in speed as sound travels through water causes the travel path to bend in the direction of lower velocity.

Sound speed profile (SSP): The sound speed profile (SSP) is a graphic representation of the sound speed versus depth of the ocean. These profiles vary with latitude, season, and time of day.

Source Level (SL): The sound transmitted into the water by a sound source, such as an active sonar ping. SL is usually measured in decibels referenced to 1 micropascal at 1 m (3.28 ft).

Take: To harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt any of these activities.

Temporary threshold shift (TTS): Temporary increases in threshold occurring after exposure to high noise levels, which can last from minutes to hours to days (Richardson et al., 1995b).

Transmission loss (TL): Energy losses as the pressure wave, or sound, travels through the water, the associated wavefront diminishes due to the spreading of the sound over an increasingly larger volume and the absorption of some of the energy by seawater.

Threatened species: Any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. Threatened species are listed in 50 CFR 17.12.

APPENDIX B

LIST OF ACRONYMS

LIST OF ACRONYMS

AT	Anti-tank
BVI	Blade Vortex Interaction
dB	Decibels
dBA	"A" weighted sound level
dB//1µPa@1m	Decibels referenced to one micropascal measured at one meter from center of source
CALFEX	Combined Arms Live-Fire Exercise
CASS	Comprehensive Acoustic System Simulation
°T	Bearing in degrees True
DoN	Department of Navy
EFD	Energy Flux Density
ESA	Endangered Species Act
FEIS	Final Environmental Impact Statement
ft	feet
GRAB	Gaussian Ray Bundle
HE	High Explosive
hr	hour
HSI	High Speed Impulsive
Hz	Hertz
kg	kilogram
kHz	kilo Hertz
km	kilometer
kt	knots (nautical miles per hour)
kyd	kiloyard
LF	Low frequency (100 – 1,000 Hz)
m	meter
MF	Mid-frequency (1,000 – 10,000 Hz)
MMR	Makua Military Reservation
ms	millisecond
MMPA	Marine Mammal Protection Act
NCDC	National Climatic Data Center
NDAA	National Defense Authorization Act
NEW	Net Explosive Weight
nm	nautical mile
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
psi	pounds per square inch
PTS	Permanent Threshold Shift
RAWS	Remote Autonomous Weather Stations
RL	Received Level
sec	second
SI	International System of Units
SMAW	Shoulder-Launched Multipurpose Assault Weapon
TL	Transmission Loss
TM	Tympanic Membrane
TTS	Temporary Threshold Shift
µPa	micropascal
USFWS	U.S. Fish and Wildlife Service
yds	yards
ZOI	Zone of Influence