# 7.0 Construction Noise Impact Assessment

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## Chapter Summary

- The project biologist must analyze the extent of noise because it is one element used to define the action area.
- The project biologist must analyze the effects of noise on all animal species addressed in the BA.
- The two most common types of in-air noise based on attenuation dynamics are point source and line source.
- Natural factors such as topography, vegetation, and temperature can reduce in-air noise over distance. A hard site exists where noise travels away from the source over a generally flat, hard surface such as water, concrete, or hard-packed soil. When ground cover or normal unpacked earth is present between the source and receptor, the ground becomes absorptive to noise energy and is called a soft site.
- Topography, vegetation, and atmospheric factors can also affect the rate of noise attenuation.
- Existing sound levels can serve as a baseline from which to measure potential disturbance caused by project activities. Baseline sound is characterized as either background or ambient sound and levels vary greatly and depend on site-specific factors.
- Most transportation projects have traffic noise as part of the site background sound levels. Identifying the amount and type of traffic helps to determine the background sound level.
- One of the hardest things to quantify is noise associated with construction activities.
- Although noise from multiple sources at the same location results in louder levels than a single source alone, decibels are measured on a logarithmic scale, so noise levels cannot be added by standard addition.
- Defining the extent of project-related noise requires the following steps:
    1. Estimate the equipment noise level for the project.
    2. Estimate the background sound level. In most cases this can be done by defining traffic noise levels in the project area. In situations where background sound levels include intermittent

peaks, try to identify the general background condition. For example, at a ferry terminal, the ferry whistle is usually the loudest background sound source. If the ferry whistle is infrequent, it would be more meaningful for the analysis to use the background condition without these peaks to compare to project-related noise. However, in cases where frequent port horns and whistles occur that consistently cause an increase to the background sound level ($L_{eq}$ (h)) then it would be inappropriate to exclude them.

3. Determine whether hard or soft site conditions exist.

4. Determine whether the construction noise is a point source or line source noise.

- Use the correct equation to solve for the distance construction noise will travel before it attenuates to the ambient or background sound level. In some instances (for example projects that are politically volatile or subjected to significant public scrutiny or those that occur in areas of extreme or highly variable topography), a project may require a more rigorous noise assessment for determining the extent of the action area.

- The Services provide threshold values for making effect determinations for some listed species. The threshold distances for in-air noise are defined as a known distance where noise at a given level elicits some response from a target species.

- The in-air noise assessment for northern spotted owls and marbled murrelets should estimate noise-only detectability thresholds, noise-only alert and disturbance thresholds, and noise-only harassment/injury thresholds. Use the correct equation to determine construction noise levels at a specific distance.

- Over long distances, water currents bend underwater noise waves upward when propagated into the current and downward downstream. Noise waves bend toward colder, denser water.

- Underwater noise levels are measured with a hydrophone, or underwater microphone, which converts sound pressure to voltage, expressed in Pascals (Pa), pounds per square inch (psi), or decibels (dB).

- Transmission loss (TL) underwater is the accumulated decrease in acoustic intensity as an acoustic pressure wave propagates outward from a source. The intensity of the noise is reduced with increasing distance due to spreading.

- Noise propagation factors in water include hydrographic conditions that affect noise transmission, such as currents or tides, sediment types, bottom topography, structures in the water, slope of the bottom, temperature gradient, and wave height.

- Existing underwater sound levels serve as a baseline from which to measure potential disturbance associated with project activities.

- When analyzing the extent of project-related noise, consider the area underwater through which the noise travels until it reaches ambient or background levels or encounters a land mass.

- The steps for defining the extent of project-related underwater noise are as follows:

  1. Determine the noise level for the project.

  2. Determine the background sound level.

  3. Determine applicable noise reduction factors.

  4. To determine the decrease in intensity of the noise away from the source, calculate noise attenuation at 4.5 dB per doubling of distance (Practical Spreading Model).

  5. Calculate the potential distance at which the project noise will attenuate to background levels, or encounter a land mass.

- For aquatic species, risk of injury or mortality resulting from noise is generally related to the effects of rapid pressure changes, especially on gas-filled spaces in the animal's body (such as swimbladder, lungs, sinus cavities, etc.).

- Generally, in-water or near-water pile driving is the issue of concern for the Services on WSDOT projects. If underwater blasting (not usually an issue for transportation projects) will occur this should also be analyzed.

- Different aquatic species exhibit different hearing ranges, so the analysis should consider whether the frequency range of the activity overlaps with that of the species. Threshold distances and noise levels have been established to be used as a basis for effect determinations for salmon, bull trout, marbled murrelet, Steller sea lion, and killer whale.

- NMFS has issued a calculator to aid in the analysis of underwater sound effects on fishes that is available on-line at: <http://www.wsdot.wa.gov/Environment/Biology/BA/BAguidance.htm#Noise>.

- USFWS has issued a calculator to aid in the analysis of underwater sound effects on diving marbled murrelets that is available on-line at the WSDOT website listed immediately above.

Noise from project activities can adversely affect wildlife in various ways. This chapter provides guidance on identifying construction-related noise and noise impacts in both terrestrial and aquatic settings. Basic acoustic concepts are covered, including noise generation, transmission, and reduction. Identifying ambient or background sound levels for comparison with anticipated project-related noise can assist the project biologist in more accurately identifying the extent of project-related noise and potential impacts on listed species.

The terms noise and sound should not be used interchangeably. *Noise* is characterized as unwanted sound, and because *ambient* and *background* sound are not considered adverse, they are not classified as noise. The ambient sound level is the total of all sound sources excluding anthropogenic sources. The background sound level is a composite of sound from all sources including anthropogenic sources. Ambient or background sound levels are the starting point for analyzing construction noise impacts such that the analysis measures and compares project-related noise to either ambient or background sound based on which best applies to existing site conditions.

Three other terms used in this chapter are *source*, *path*, and *receiver*. The source is where a sound comes from, the path is the intervening terrain and factors that help to reduce the noise, and the receiver is the targeted recipient of the noise (e.g., human, eagle, microphone, etc.).

This discussion focuses on identifying the extent of project-related noise, which represents one element of the project action area, and the potential for noise impacts on wildlife. Noise transmission through air and noise impacts on terrestrial species are addressed first. Next, underwater noise, sound pressure levels, and their effects on fish, diving marine birds, and marine mammals are discussed.

## 7.1 Terrestrial Noise

Noise is transmitted through air when an object moves, like water flowing over rocks, or air passing through vocal cords. This movement causes air waves, similar to ripples in water. When these waves reach an animal's ears, they are perceived as sound. Sound is usually measured in decibels (dB). A decibel is a relative measure, not an absolute measure, that is accompanied by a reference scale (dB = 20 * log (P1/Pr), where P1 is the measured noise pressure and Pr is the reference pressure) to denote the Sound Pressure Level (SPL).

In-air noise when frequency-weighted to approximate human hearing is measured on an A-weighted scale, denoted as dBA.[1] The A-weighted decibel scale begins at zero, which

1 For sound pressure in air, the reference pressure is usually 20 micro-Pascal (μPa). One Pascal is the pressure resulting from a force of 1 newton exerted over an area of 1 square meter. Sound measured in air scale is referenced to 20 μPa in this document.

represents the faintest sound level that humans with normal hearing can hear. Decibels are measured on a logarithmic scale so each 10 dB increase doubles the sound; therefore a noise level of 70 dBA is twice as loud to the listener as a noise of 60 dBA (USDOT 1995). Table 7-1 shows typical noise levels generated by common indoor and outdoor activities, and provides possible human responses.

**Table 7-1. Typical noise levels and possible human responses.**

| Common Noises | Noise Level (dBA) | Effect |
|---|---|---|
| Rocket launching pad (no ear protection) | 180 | Irreversible hearing loss |
| Carrier deck jet operation<br>Air raid siren | 140 | Painfully loud |
| Thunderclap | 130 | Painfully loud |
| Jet takeoff (200 feet)<br>Auto horn (3 feet) | 120 | Maximum vocal effort |
| Pile driver<br>Rock concert | 110 | Extremely loud |
| Garbage truck<br>Firecrackers | 100 | Very loud |
| Heavy truck (50 feet)<br>City traffic | 90 | Very annoying<br>Hearing damage (8 hours of exposure) |
| Alarm clock (2 feet)<br>Hair dryer | 80 | Annoying |
| Noisy restaurant<br>Freeway traffic<br>Business office | 70 | Telephone use difficult |
| Air conditioning unit<br>Conversational speech | 60 | Intrusive |
| Light auto traffic (100 feet) | 50 | Quiet |
| Living room<br>Bedroom<br>Quiet office | 40 | Quiet |
| Library/soft whisper (15 feet) | 30 | Very quiet |
| Broadcasting studio | 20 | Very quiet |
| | 10 | Just audible |
| Threshold of hearing | 0 | Hearing begins |

From: <http://www.nonoise.org/resource/educat/ownpage/soundlev.htm>.

## 7.1.1 Noise Generation, Transmission, and Reduction

### *7.1.1.1 Noise Sources*

Noise is a pressure wave that decreases in intensity over distance from the source. Noise attenuation is generally described as a reduction in decibel level per doubling of distance from the source. Depending on the nature of the noise source, noise propagates at different rates. When reporting the noise level from a source, one should always specify the reference distance from the source for the sound measurement or estimated source. A standard reference distance for source noise levels is 50 feet. The two most common types of noise are point source and line source. These are discussed in more detail below.

*Point Source Noise*

Point source noise is usually associated with a source that remains in one place for extended periods of time, such as with most construction activities. A few examples of point sources of noise are pile drivers, jackhammers, rock drills, or excavators working in one location. However, noise from a single traveling vehicle is also considered a point source noise.

Construction point source noise is commonly measured by maximum decibel level ($L_{max}$), or the highest value of a sound pressure over a stated time interval (Harris 1991). Noise from a point source spreads spherically over distance. Think of this as a 3-dimensional model, where the wave spreading creates a dome effect, traveling in all directions equally from the source. The standard reduction for point source noise is 6 dB per doubling of distance from the source.

*Line Source Noise*

Line source noise is generated by moving objects along a linear corridor. Highway traffic is a good example of line source noise. When assessing line source noise levels the analyst should measure or estimate over longer time periods such as the $L_{eq}$(h) rather than in maximum levels such as the $L_{max}$ measured for point source noise. Only when noise comes from a very long continuous noise source such as a very long conveyor belt should the line source be represented by maximum event levels such as ($L_{max}$).

Noise from a line source spreads cylindrically, spreading outward along the length of a line. The standard reduction for line source noise is 3 dB per doubling of distance from the source (compared to 6 dB for construction point source noise).

Table 7-2 provides an example of noise attenuation of construction point and line source decibel levels based on distance from the source.

#### *7.1.1.2 Noise Path Reduction Factors*

Natural factors such as topography, vegetation, and temperature can further reduce noise over distance. This section covers a few of the common factors and their applicability in increasing the noise reduction per doubling of distance from the source.

*Hard Site versus Soft Site*

A hard site exists where noise travels away from the source over a generally flat, hard surface such as water, concrete, or hard-packed soil. These are examples of reflective ground, where the ground does not provide any attenuation. The standard attenuation rate for hard site conditions is

6 dB per doubling of distance for point source noise and 3 dB per doubling of distance from line sources.

**Table 7-2. Example of noise reduction over distance from a 95 dBA source showing variation between construction point source and line source.**

| | Noise Attenuation | |
|---|---|---|
| Distance from Source (feet) | Point Source (–6 dB) | Line Source (–3 dB) |
| 50 | 95 dBA | 95 dBA |
| 100 | 89 dBA | 92 dBA |
| 200 | 83 dBA | 89 dBA |
| 400 | 77 dBA | 86 dBA |
| 800 | 71 dBA | 83 dBA |
| 1,600 | 65 dBA | 80 dBA |
| 3,200 | 59 dBA | 77 dBA |
| 6,400 | 53 dBA | 74 dBA |

When ground cover or normal unpacked earth (i.e., a soft site) exists between the source and receptor, the ground becomes absorptive of noise energy. Absorptive ground results in an additional 1.5 dB reduction per doubling of distance as it spreads from the source. Added to the standard reduction rate for soft site conditions, point source noise attenuates at a rate of 7.5 dB per doubling of distance, and line source noise decreases at a rate of 4.5 dB per doubling of distance.

*Topography, Vegetation, and Atmospheric Factors*

A break in the line of sight between the noise source and the receptor can result in a 5 dB reduction. Dense vegetation can reduce noise levels by as much as 5 dB for every 100 feet of vegetation, up to a maximum reduction of 10 dB over 200 feet (USDOT 1995). Atmospheric conditions can also affect the rate of noise attenuation. Noise travels farther during periods of higher humidity and also in colder temperatures (USDI 2003). Wind can reduce noise levels by as much as 20 to 30 dB at long distances (USDOT 1995).

The influences of vegetation, topography, and atmospheric conditions as noise reduction factors can vary greatly so are difficult to include in an analysis. Therefore, these factors are generally not taken into account in environmental noise analyses over short distances. As a result, such analyses are conservative and likely to predict noise levels that are higher than actual noise levels.

### 7.1.2 Ambient or Background Sound Conditions

As defined for this manual, ambient sound level is the total of all sound sources in a specific area excluding anthropogenic sources. The background sound level is a composite of sound from all sources including anthropogenic sources. Either the ambient or background sound level is selected as the baseline for evaluating construction noise impacts based on existing site conditions.

#### 7.1.2.1 Existing Conditions

Determining background or ambient sound levels the first step for a noise assessment. It can vary greatly depending on site-specific factors. Environmental factors can elevate background sound near the source, effectively hiding, or masking construction noise. The same environmental factors occurring near the receiver can change the receiver's perception of how loud construction noise is, or hide it completely.

Background and ambient sound levels vary by location even for undisturbed forested areas. A WSDOT noise analyses on the San Juan Islands identified an ambient level of about 35 dBA, with regular noise intrusions from traffic and aircraft overflights ranging from 45 to 72 dBA (WSDOT 1994). A study on the Mt. Baker-Snoqualmie National Forest listed forested ambient levels between 52 and 60 dBA (USDA Forest Service 1996). The Olympic National Forest programmatic biological assessment uses an estimated ambient level of 40 dBA for undisturbed forested areas (USDI 2003). The environment surrounding transportation projects is often composed of high-speed highways, busy ferry terminals, and urban development. For projects occurring in these areas, background sound levels will be much higher than that of a forested or undeveloped setting (see Section 7.1.4.1).

Weather conditions such as wind or rainfall can increase ambient sound in undeveloped areas. Locations near rivers or streams have higher ambient sound levels as well. As with the atmospheric conditions described above, environmental factors are so variable that models rarely take them into account.

The WSDOT project biologist should check with the WSDOT project manager to see if ambient or background sound data are available for the project or similar areas. If ambient or background information is not available and noise may be a major concern in the consultation, the biologist should have ambient or background sound within the project area measured by a professional.

#### 7.1.2.2 Traffic Noise

The majority of projects assessed by a project biologist will include background traffic noise. Identifying the amount and type of traffic helps to determine the background sound level. The level of highway traffic noise depends upon the traffic volume, the vehicle speeds, and the mix of trucks in the flow of traffic (USDOT 1995). Generally, the loudness of traffic noise is increased when traffic is heavier, when traffic speed is increased, and when a greater proportion of the traffic flow is heavy trucks.

For traffic volume, 2,000 vehicles per hour sounds twice as loud as (or is 10 dBA higher than) 200 vehicles per hour (USDOT 1995). For traffic speed, traffic at 65 miles per hour (mph) sounds twice as loud as traffic at 30 mph (USDOT 1995). In regard to the proportion of heavy truck traffic, one truck at 55 mph sounds as loud as 28 cars at 55 mph (USDOT 1995).

Vehicle noise comes from a combination of sources produced by engines, exhaust, and tires. The loudness of vehicle noise can also be affected by the condition and type of roadway, road grade, and the condition and type of vehicle tires.

Table 7-3 lists typical traffic noise levels for a variety of traffic volumes at various speeds, assuming 4 percent medium trucks, 6 percent heavy trucks, and a sound level modeled at 50 feet from the source. These numbers would be elevated as the percent of truck traffic volume increases. The State Highway Log can be used to find the posted speed for a state route. The Annual Traffic Report can be used to find the traffic volume, where traffic volume in vehicles per hour is equal to 10 percent of the Average Daily Traffic (ADT).

**Table 7-3. Typical noise levels for traffic volumes at a given speed.**

| Volume (vehicles/hour) | Sound Level (dBA $L_{eq}$ (hour)) at 50 feet | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 125 | 57.3 | 58.5 | 59.7 | 60.9 | 62.0 | 63.1 | 63.8 | 64.1 | 64.5 | 65.1 | 65.2 | 66.1 |
| 250 | 60.2 | 61.4 | 62.6 | 63.8 | 64.9 | 66.0 | 66.7 | 67.0 | 67.4 | 68.0 | 68.2 | 69.0 |
| 500 | 63.2 | 64.4 | 65.6 | 66.8 | 67.9 | 69.0 | 69.7 | 70.0 | 70.4 | 71.0 | 71.2 | 72.0 |
| 1,000 | 66.2 | 67.4 | 68.6 | 69.8 | 70.9 | 72.0 | 72.7 | 73.0 | 73.5 | 74.0 | 74.2 | 75.0 |
| 2,000 | 69.2 | 70.4 | 71.6 | 72.8 | 73.9 | 75.0 | 75.7 | 76.1 | 76.5 | 77.0 | 77.2 | 78.0 |
| 3,000 | 71.0 | 72.2 | 73.4 | 74.6 | 75.7 | 76.8 | 77.5 | 77.8 | 78.2 | 78.8 | 79.0 | 79.8 |
| 4,000 | 72.2 | 73.4 | 74.6 | 75.8 | 76.9 | 78.0 | 78.7 | 79.1 | 79.5 | 80.1 | 80.2 | 81.0 |
| 5,000 | 73.2 | 74.4 | 75.6 | 76.8 | 77.9 | 79.0 | 79.7 | 80.0 | 80.4 | 81.0 | 81.2 | 82.0 |
| 6,000 | 74.0 | 75.2 | 76.4 | 77.6 | 78.7 | 79.8 | 80.5 | 80.8 | 81.2 | 81.8 | 82.0 | 82.8 |
| **Speed (miles/hour)** | 35 | 40 | 45 | 50 | 55 | 60 | 65 / T60 | 65 | 70 / T60 | 70 | 75 / T60 | 75 |

T is the speed limit for truck traffic when it is posted differently from other vehicle traffic.

The State Highway Log is available at <http://www.wsdot.wa.gov/mapsdata/roadway/statehighwaylog.htm>; and the Annual Traffic Report is available at <http://www.wsdot.wa.gov/mapsdata/travel/annualtrafficreport.htm>.

### 7.1.3 Construction Noise

One of the easiest things for the project biologist to identify and one of the hardest things to quantify is noise associated with the actual construction of the project. How much noise will construction generate, how often will it occur, and how long it will last, are all questions that should be answered in the assessment. This section provides an introduction to equipment noise characteristics that the project biologist can use for typical construction projects.

Construction is usually performed in a series of steps or phases, and noise associated with different phases can vary greatly. However, similarities in noise sources allow typical construction equipment to be placed into one of three categories: heavy equipment, stationary equipment, or impact equipment.

### *7.1.3.1 Heavy Equipment*

Analysts can categorize heavy equipment as earth-moving equipment, such as excavating machinery like excavators, backhoes, and front loaders, as well as materials handling equipment like graders, pavers, rollers, and dump trucks. Average maximum noise levels ($L_{max}$) at 50 feet from heavy equipment range from about 73 to 101 dBA for non-impact equipment (Table 7-4). These numbers were identified from several studies, and represent average maximum noise levels of reported values. During a phase of construction using heavy equipment, noise is generated more or less at a constant level. Therefore, noise levels can be quantified based on an average hourly level.

Lacking onsite noise level data, the project biologist should use the worst-case scenario of the known equipment noise levels for a noise analysis. Manufacturers may also provide noise levels for their equipment, but the biologist must know the specific make and model of the equipment to be used for the project in order to obtain that information. Care should be taken to identify the distance at which the manufacturer has measured the equipment and ensure that the sound levels are provided as $L_{eq}$ or $L_{max}$ and not as a sound power level.

### *7.1.3.2 Stationary Equipment*

Stationary equipment such as pumps, power generators, and air compressors generally run continuously at relatively constant power and speeds. Noise levels at 50 feet from stationary equipment can range from 68 to 88 dBA, with pumps typically in the quieter range. The biologist can also assume an averaged noise level for stationary equipment because of its fixed location and constant noise pattern.

### *7.1.3.3 Impact Equipment*

Impact equipment includes pile drivers, jackhammers, pavement breakers, rock drills, and other pneumatic tools where a tool bit touches the work. The noise from jackhammers, breakers, rock drills, and pneumatic tools comes from the impact of the tool against material. These levels can vary depending on the type and condition of the material. Noise levels at 50 feet from impact equipment, including pile drivers, jackhammers, and rock drills can range from 79 to 110 dBA. Blasting may be associated with impact equipment use and that noise can reach 126 dBA.

An impact pile-driving hammer is a large piston-like device that is usually attached to a crane. The power source for impact hammers may be mechanical (drop hammer), air steam, diesel, or hydraulic.

Most impact pile driver hammers have a vertical support that holds the pile in place, and a heavy weight, or ram, moves up and down, striking an anvil that transmits the blow of the ram to the pile. In hydraulic hammers, the ram is lifted by fluid, and gravity alone acts on the down stroke.

**Table 7-4. Average maximum noise levels at 50 feet from common construction equipment.**

| Equipment Description | Impact Device? | Actual Measured Average $L_{max}$[b] at 50 feet |
|---|---|---|
| Auger Drill Rig | No | 84 |
| Backhoe | No | 78 |
| Blasting (rock slope production) [a] | Yes | 126 |
| Blasting (mitigated rock fracturing) [a] | Yes | 98 |
| Boring Jack Power Unit | No | 83 |
| Chain Saw | No | 84 |
| Clam Shovel (dropping) | Yes | 87 |
| Compactor (ground) | No | 83 |
| Compressor (air) | No | 78 |
| Concrete Mixer Truck | No | 79 |
| Concrete Pump Truck | No | 81 |
| Concrete Saw | No | 90 |
| Crane | No | 81 |
| Dozer | No | 82 |
| Drill Rig Truck | No | 79 |
| Drum Mixer | No | 80 |
| Dump Truck | No | 76 |
| Excavator | No | 81 |
| Flat Bed Truck | No | 74 |
| Front End Loader | No | 79 |
| Generator | No | 81 |
| Generator (<25KVA, VMS signs) | No | 73 |
| Gradall | No | 83 |
| Grader [a] | No | 89 |
| Grapple (on backhoe) | No | 87 |
| Horizontal Boring Hydr. Jack | No | 82 |
| Impact Pile Driver [a] | Yes | 110 |
| Jackhammer | Yes | 89 |
| Man Lift | No | 75 |
| Mounted Impact Hammer (hoe ram) | Yes | 90 |
| Pavement Scarafier | No | 90 |
| Paver | No | 77 |
| Pickup Truck | No | 75 |
| Pneumatic Tools | No | 85 |
| Pumps | No | 81 |
| Refrigerator Unit | No | 73 |
| Rivet Buster/chipping gun | Yes | 79 |
| Rock Drill | No | 81 |
| Roller | No | 80 |

**Table 7-4 (continued). Average maximum noise levels at 50 feet from common construction equipment.**

| Equipment Description | Impact Device? | Actual Measured Average $L_{max}$[b] at 50 feet |
|---|---|---|
| Sand Blasting (Single Nozzle) | No | 96 |
| Scraper | No | 84 |
| Shears (on backhoe) | No | 96 |
| Slurry Plant | No | 78 |
| Slurry Trenching Machine | No | 80 |
| Tractor[a] | No | 84 |
| Vacuum Excavator (Vac-truck) | No | 85 |
| Vacuum Street Sweeper | No | 82 |
| Ventilation Fan | No | 79 |
| Vibrating Hopper | No | 87 |
| Vibratory Concrete Mixer | No | 80 |
| Vibratory Pile Driver | No | 101 |
| Warning Horn | No | 83 |
| Water Jet Deleading | No | 92 |
| Welder / Torch | No | 74 |

[a] WSDOT measured data in FHWA's Roadway Construction Noise Mode Database (2005).
[b] $L_{max}$ is the maximum value of a noise level that occurs during a single event.

A diesel hammer, or internal combustion hammer, carries its own power source and can be open-end or closed-end. An open-end diesel hammer falls under the action of gravity alone. A closed-end diesel hammer (double-acting) compresses air on its upward stroke and therefore can operate faster than open-end hammers.

Vibratory pile driver hammers are also used on projects. A vibratory pile-driving hammer has a set of jaws that clamp onto the top of the pile. The pile is held steady while the hammer vibrates the pile to the desired depth. Because vibratory hammers are not impact tools, noise levels are typically not as high as with impact pile drivers. However, piles installed with a vibratory hammer must often be proofed, which involves striking the pile with an impact hammer to determine its load-bearing capacity, possibly with multiple impacts. The project biologist should check with the design engineer to determine if impact driving or proofing of the piles will be needed. If so, the project biologist should include proofing noise from impact pile driving in the assessment.

Although stationary equipment noise and heavy equipment noise can be averaged over a period of time, impact pile driving noise consists of a series of peak events. Generally, noise from impact pile driving is reported at maximum levels. The loudest in-air noise from impact pile driving results from the impact of the hammer dropping on the pile, particularly when hollow steel piles are used. Though noise levels are variable during pile driving, to be conservative (more protective of the listed species), the project biologist should assume that noise at the highest levels documented is generated by impact pile driving and should avoid using an average in a noise assessment.

When conducting an in-air noise assessment involving impact driving of hollow steel piles, USFWS currently recommends assuming a noise level of 115 dBA $L_{max}$ at 50 feet (for 30-inch piles) (Visconty 2000) as a worst-case scenario, where $L_{max}$ is the maximum value of a noise level that occurs during a single event. Most of the documented studies have maximum decibel levels between 95 and 115 dBA, with only one documented level above 115 dBA. Noise assessments by WSDOT have documented maximum levels of 103 dBA for 24-inch piles and 110 dB for 30-inch piles each measured at a range of 11 meters (Illingworth and Rodkin 2010). If site-specific information is available, or smaller diameter piles are used, it may be appropriate to substitute lower values.

When assessing in-air noise for pinnipeds, un-weighted Root Mean Square (RMS) sound level should be used to compare to the un-weighted RMS threshold values. Assessments by WSDOT have documented un-weighted RMS levels for a vibratory hammer to be between 88 dB (18-inch pile) and 98 dB (30-inch pile) at 50 feet (Laughlin 2010). Un-weighted RMS impact hammer in-air sound levels were between 98 dB and 102 dB at 50 feet for 72-inch piles (Laughlin 2011).

Noise from blasting should be included in the discussion on impact equipment. Since blast noise typically is infrequent and of short duration, blast noise is generally assessed using a different noise metric than what is used for other more continuous types of noise. Blasting can occur in different situations and a variety of methods may be used. Due to the variability in blasting situations and techniques, noise from blasting is not fully addressed in this chapter. However, when blasting noise is part of a project, the project biologist should consider the following factors:

- Substrate – The location where blasting occurs partially determines the size of the charge and the duration of blasting. Blasting through bedrock requires more time and effort than blasting through less dense substrate.
- Size of charge – Blasting can use charges of less than a pound to over 200 pounds.
- Detonation system – Precision blasting may use a sequential delay system where each blast is subdivided into many smaller blasts, separated by a few milliseconds; or the blast may occur all at once.
- Directivity – Blasting above ground acts like point-source noise and spreads spherically from the source. Where blasting occurs below ground level, as in a shaft or pit, some directivity occurs, which directs the force of the blast upward more than horizontally, thereby lessening impacts.
- Use of BMPs – Best management practices may be used to lessen the energy of the blast. For example, when the charge is small enough, the use of heavy mats to cover the charge can significantly reduce the blast energy and contain any flying debris.

#### *7.1.3.4 Rules for Decibel Addition*

Now that the project biologist can identify the type and level of construction equipment noise, it is important to discuss what happens when several pieces of equipment are operating at one time. Although noise from multiple sources at the same location results in louder levels than a single source alone, the decibel is measured on a logarithmic scale, so noise levels cannot be added by standard addition. Two noises of equal level (±1 dB) combine to raise the noise level by 3 dB. However, if two noises differ by more than 10 dB, there is no combined increase in the noise level; the higher output covers any other noise. The rules for decibel addition are shown in Table 7-5.

**Table 7-5. Rules for combining noise levels.**

| When two decibel values differ by: | Add the following to the higher decibel value: |
|---|---|
| 0 or 1 dBA | 3 dBA |
| 2 or 3 dBA | 2 dBA |
| 4 to 9 dBA | 1 dBA |
| 10 dBA or more | 0 dBA |

Source: USDOT (1995).

To determine the combined noise level of all construction equipment operating together, the project biologist should find the three pieces of equipment with the loudest noise levels, add the two lowest levels together using the rules of decibel addition as is shown in Table 7-5, then add the result to the third noise level using the same rules in Table 7-5. For Example: a project's three loudest pieces of equipment have noise levels of 80, 79, and 70 dBA. Add the two lowest pieces of equipment using Table 7-5: 79 – 70 = 9; therefore 1 dBA is added to79 dBA, resulting in a combined noise level of 80 dBA. Add 80 dBA to the next loudest piece of equipment using Table 7-5: 80 – 80 is a difference of 0 or more; therefore 3 dBA is added to 80 dBA, resulting in a total noise level for all equipment combined of 83 dBA.

### 7.1.4 Determining the Extent of Project Related Noise

This discussion has introduced basic concepts and provided information on construction-related noise, traffic noise, and baseline sound levels. Using this information, the project biologist should be able to identify the extent of project-related noise, which constitutes one element defining the project action area. This section provides instructions for establishing the extent of noise and defining the noise element of the action area.

#### *7.1.4.1 Determining the Background Sound Level*

As part of the noise assessment, it is important to identify the background or ambient sound level throughout the area where construction noise is expected to extend. For transportation projects, traffic noise frequently exceeds the ambient sound level in the project area. However, in highly urbanized areas, other sounds may exceed traffic noise levels. Similarly, for projects in rural areas with little or no traffic, background sound levels also may not be defined by traffic noise.

Background sound levels vary depending on the level of development. Urban areas have the highest background sound levels, with daytime levels approximating 60 to 65 dBA (EPA 1978). Suburban or residential areas have background levels around 45 to 50 dBA (EPA 1978), while rural areas are the quietest with sound levels of 35 to 40 dBA (EPA 1978). In a more recent study, Cavanaugh and Tocci (1998) identify typical urban residential background sound at around 65 dBA, high-density urban areas at 78 dBA, and urban areas adjacent to freeway traffic at 88 dBA. These sound levels may be important in a project noise assessment if traffic is absent near the project site or if construction noise extends beyond the extent of traffic background sound. In this case, the project biologist can use Table 7-6, which lists daytime sound levels, exclusive of traffic, based on population density to determine the background sound level.

In urban and developed areas, traffic noise and construction noise attenuate (decline) to background in less distance than in undeveloped or rural areas. For example, it may take 2 miles or more for construction noise to reach background levels in a rural area, but the same noise may attenuate to urban background levels in less than a mile. For many transportation projects, however, traffic noise determines the background sound level.

**Table 7-6. Estimating existing environmental background noise levels.**

| Population Density (people per square mile) | $L_{eq}$[a] Daytime Noise Levels Exclusive of Traffic (dBA) |
|---|---|
| 1-100 | 35 |
| 100-300 | 40 |
| 300-1,000 | 45 |
| 1,000-3,000 | 50 |
| 3,000-10,000 | 55 |
| 10,000-30,000 | 60 |
| 30,000 and up | 65 |

Source: FTA (2006).

[a] Where $L_{eq}$ is the *equivalent sound pressure level*: the steady noise level that, over a specified period of time, would produce the same energy equivalence as the fluctuating noise level actually occurring.

A general guideline is:

- If the distance where traffic noise attenuates to ambient or background levels is greater than the distance where construction noise attenuates to ambient or background levels, then the extent of construction noise is equal to the distance where construction noise attenuates to traffic noise levels. In this scenario, traffic noise from the roadway extends farther than construction noise. The extent of project noise is then calculated to where it attenuates to the traffic noise level, which is the dominant background sound. In this case, traffic noise is louder than ambient or background levels, and construction noise is audible until it attenuates to the same level as traffic noise.
- Conversely, if the distance where traffic noise attenuates to ambient or background levels is less than the distance where construction noise attenuates to ambient or background levels, then the extent of construction noise is equal to the distance where construction noise attenuates to ambient or background levels. In this case, construction noise extends farther than traffic noise from the roadway. The extent of project noise is then calculated to where it attenuates to the surrounding ambient or background levels. In this case, construction noise dominates until it attenuates to the same level as surrounding ambient or background sound.

Table 7-7 displays this relationship.

**Table 7-7. Extent of project-related noise based on attenuation to the dominant background level.**

| If the distance noise attenuates: | | | The distance noise attenuates: | | | The distance of the extent of construction noise is based on attenuation: | |
|---|---|---|---|---|---|---|---|
| From | To | | From | To | | From | To |
| Traffic | Ambient/Background | > | Construction | Ambient/Background | Then | Construction | Traffic |
| Traffic | Ambient/Background | < | Construction | Ambient/Background | Then | Construction | Ambient/Background |

### *7.1.4.2 Equations for Solving Distances*

Base 10-Log equations are used to calculate noise levels at a specific distance from the source (such as construction noise levels at a nest located 650 feet from a project), to determine the distance construction noise will travel before it attenuates to the traffic noise level, and also to determine the distance at which construction or traffic noise will attenuate to background or ambient sound levels.

To determine construction noise levels at a specific distance, the following equation should be used:

$$\mathbf{L_{max} = Construction\ L_{max}\ at\ 50\ feet - 25 * Log(D/D_o)}$$

Where $L_{max}$ = highest A-weighted sound level occurring during a noise event during the time that noise is being measured.
At 50 feet = the reference measurement distance (standard is 50 feet)
D = the distance from the noise source
$D_o$ = the reference measurement distance (50 feet in this case)

***Example*** *– Project-related noise is estimated at 84 dBA, and traffic noise is estimated at 66 dBA with 40 dBA for ambient sound in a forested site (soft site). A spotted owl nest is located 650 feet from the project. What is the expected construction noise level at the nest site?*

*$L_{max}$ = Construction $L_{max}$ at 50 feet – 25 * Log($D/D_o$)*
*Where $L_{max}$ = 84 dBA*
*D = 650*
*$D_o$ = the reference measurement distance (50 feet in this case)*

*$L_{max}$ = 84 dBA at 50 feet – 25 * Log(650/50)*
*$L_{max}$ = 84 dBA at 50 feet – 25 * Log(13)*
*$L_{max}$ = 84 dBA at 50 feet – 27.85*
*$L_{max}$ = 56.15 dBA*

To determine the distance point source construction noise will travel before it attenuates to the ambient sound level; the following equation should be used:

$$\mathbf{D = Do * 10^{((Construction\ Noise\ -\ Ambient\ Sound\ Level\ in\ dBA)/\alpha)}}$$

Where D = the distance from the noise source
$D_o$ = the reference measurement distance (50 feet in this case)
α = 25 for soft ground and 20 for hard ground. For point source noise, a spherical spreading loss model is used. These alpha (α) values assume a 7.5 dBA reduction per doubling distance over soft ground and a 6.0 dBA reduction per doubling distance over hard ground.

***Example** – Project-related noise is estimated at 84 dBA, and traffic noise is estimated at 66 dBA with 40 dBA for ambient sound in a forested site (soft site). At what distance will construction noise attenuate to the ambient sound level over soft ground?*

$D = D_o * 10^{((\text{Construction Noise – Ambient Sound in dBA})/\alpha)}$
$D_o$ *= the reference measurement distance (50 feet in this case)*
$D = 50 * 10^{((84 - 40)/25)}$
$D = 50 * 10^{(44/25)}$
$D = 50 * 10^{(1.76)}$
$D = 50 * 57.54$
*D=2,877 feet (about 0.5 miles)*

To determine the distance line source traffic noise will travel before it attenuates to the ambient sound level, the following equation should be used:

$$\mathbf{D = Do * 10^{((\text{Traffic Noise – Ambient Sound Level in dBA})/\alpha)}}$$

Where D = the distance from the traffic noise
$D_o$ = the reference measurement distance (50 feet in this case)
α = 15 for soft ground and 10 for hard ground. For line source noise, a cylindrical spreading loss model is used. These alpha (α) values assume a 4.5 dBA reduction per doubling distance over soft ground and a 3.0 dBA reduction per doubling distance over hard ground.

***Example** – Project-related noise is estimated at 84 dBA, and traffic noise is estimated at 66 dBA with 40 dBA for ambient sound in a forested site (soft site). At what distance will traffic noise attenuate to the ambient sound level over soft ground?*

$D = D_o * 10^{((\text{Traffic Noise – Ambient Sound in dBA})/\alpha)}$
$D_o$ *= the reference measurement distance (50 feet in this case)*
$D = 50 * 10^{((66 - 40)/15)}$
$D = 50 * 10^{(69/15)}$
$D = 50 * 10^{(1.733)}$
$D = 50 * 53.703$
*D= 2,685 feet (0.5 miles)*

To determine the distance point source construction noise will travel before it attenuates to the traffic noise level, the following equation should be used:

$$\mathbf{D = Do * 10^{((\text{Construction Noise – Traffic Noise in dBA})/\alpha)}}$$

Where D = the distance from the noise source
$D_o$ = the reference measurement distance (50 feet is the standard)
α = 10. For the equation where you have Construction Noise – Traffic Noise in dBA / alpha; alpha will always be 10. The reason is that construction noise will be 20 for a point source over hard ground or 25 for a point source over soft ground and traffic is a line source which is 10 for

hard ground or 15 for soft ground. When you subtract the two, the result is either 25-15 = 10 or 20-10=10. Either way it will always be 10.

***Example** – Project-related noise is estimated at 84 dBA, and traffic noise is estimated at 66 dBA with 40 dBA for ambient sound in a forested site (soft site). At what distance will construction noise attenuate to the same level as traffic over soft ground?*

$D = D_o * 10^{((\text{Construction Noise – Traffic Noise in dBA})/\alpha)}$
$D_o$ = *the reference measurement distance (50 feet in this case)*
$D = 50 * 10^{((84 – 66)/10)}$
$D = 50 * 10^{(18/10)}$
$D = 50 * 10^{(1.8)}$
$D = 50 * 63$
*D= 3,154 feet (0.6 miles)*

To determine what the sound level would be at this distance (3,154 feet), we would use our first equation ($L_{max}$ = Construction $L_{max}$ at 50 feet – 25 * Log(D/$D_o$) as follows:

$L_{max}$ = *Construction* $L_{max}$ *at 50 feet – 25 * Log(D/*$D_o$*)*
$L_{max}$ = *84 dBA at 50 feet – 25 * Log(3154/50)*
$L_{max}$ = *84 dBA at 50 feet – 25 * Log(63)*
$L_{max}$ = *84 dBA at 50 feet – 25 * 1.8*
$L_{max}$ = *84 dBA at 50 feet – 44*
$L_{max}$ = *40 dBA*

#### *7.1.4.3 Steps for Defining the Extent of Project-Related Noise*

The following subsection provides instructions for performing a noise assessment to determine the extent of project-related noise defining the action area. Remember that noise is just one element of the project that must be considered when determining the action area. See Chapter 8 for guidance on other elements that should be considered.

The following information is provided in a step-by-step format with an accompanying example project. The noise assessment outlined below is appropriate for the vast majority of WSDOT projects.

1. **Estimate the equipment noise level for the project**. In order to estimate the noise level of project activities, it is imperative to know and understand all equipment that will be used for the specific project. The project biologist should avoid assuming the types of equipment that may be used and ask the project design or engineering office for specific information. Once all project equipment is known, use the decibel levels for common construction equipment found in Table 7-4. This table shows the noise range for similar construction equipment. If specific noise levels are not known, take the noise level shown for at least the three noisiest pieces of equipment listed in

the table. Remember to use the rules of decibel addition for the final project noise level. This method provides a conservative estimate, since not all equipment will be operating at the same time and location in most cases.

- ***Example** – The equipment used will be an excavator, heavy trucks, finish grader, and paver. The estimated worst-case scenario noise level for the construction equipment is: excavator, 81 dBA; dump trucks, 76 dBA; and paver, 77 dBA. The two pieces of equipment producing the least noise (dump truck at 76 dBA, and paver at 77 dBA) are added together for a difference of 1. Using the rules for decibel addition (see Table 7-5), add the 3 decibels to the highest value between the two (paver at 77 dBA) to get 80 dBA. Continuing with the rules of decibel addition, add 3 dBA to the piece of equipment with the highest noise level, the excavator at 81 dBA. Therefore, construction noise can be assumed to not exceed 84 dBA at 50 feet.*

2. **Estimate the background community or ambient sound level.** In more remote locations, background or ambient sound conditions are likely lower than traffic noise (see Section 7.1.2.1). In urban areas, community background sound may be greater than traffic noise, such as adjacent to airports. By using the information in Section 7.1.4.1, it is possible to estimate the community background sound level for the project area, based on population density.

   - ***Example** – The project is located on SR 101 in the vicinity of MP 216 in an undeveloped forested area. Based on the Olympic National Forest programmatic biological assessment, estimated ambient sound levels for undisturbed forested areas is 40 dBA (USDI 2003).*

3. **Estimate the traffic noise level.** A noise discipline report may be available and contain project specific traffic noise levels. If one is not available the information in Section 7.1.2.1, can be used to estimate the traffic noise level for the project area by assessing traffic. The project biologist should define the ADT and the speed limit in the project area. If the ADT and speed limit are not obvious, consult the Annual Traffic Report (<http://www.wsdot.wa.gov/mapsdata/travel/annualtrafficreport.htm>) and the Washington State Highway Log (<http://www.wsdot.wa.gov/mapsdata/roadway/statehighwaylog.htm>), respectively, for information. Take 10 percent of the ADT to find the approximate worse case number of vehicles per hour. Use the closest fit from Table 7-3 for vehicles per hour and speed to estimate the decibel level of traffic in the project area. Remember that seasonal use of the roadway and the amount of heavy truck traffic can raise or lower typical noise levels. If your project does not fit Table 7-3 or there are significant topographic

features in the area, then the project biologist should contact the WSDOT project office they are working with to ask if any acoustical monitoring has occurred in the project vicinity or in similar areas.

***Example*** *– The project is located on SR 101 in the vicinity of MP 216 in an undeveloped forested area. The speed limit in the project area is 60 mph; traffic levels will be elevated due to seasonal use and will include heavy truck traffic. The Annual Traffic Report lists the ADT on SR 101 at MP 216 at 2,000 vehicles per day. Therefore, vehicles per hour (vph) can be estimated as 10 percent of 2,000 or approximately 200 vph. Table 7-3 lists the noise level as 66 dBA for a roadway with 250 vph and a 60 mph traffic speed, which is the best fit for the example.*

4. **Determine whether hard or soft site conditions exist.** Section 7.1.1.2 describes the difference between hard and soft site conditions. A hard site exists where noise travels away from the source over a generally flat, hard surface such as water, concrete, or hard-packed soil. When ground cover or normal unpacked earth exists between the source and receptor, the ground becomes absorptive to noise energy and soft site conditions are present. Most project areas, other than sites adjacent to water or in developed areas having more than 90 percent concrete or asphalt, exhibit soft site conditions. For soft site conditions, add 1.5 dBA to the standard reduction factor.

    - ***Example*** *–Based on the location of the project in a forested setting, it can be assumed that soft site conditions exist. Therefore, add the additional 1.5 dBA reduction to the standard reduction factors.*

5. **Determine whether the noise is point source or line source.** Use Section 7.1.1.1 to determine whether construction noise and traffic noise are point or line source. Typically, construction noise has a point source, regardless of the activity. Even moving projects such as pavers attenuate noise in point source dynamics. Although construction activity may move, the noisy activity typically remains in one location.

    If multiple noisy activities are occurring at different locations throughout the project area, the extent of project-related noise should be described at each location. For example, pile driving could be occurring at one location in the project corridor, while pavement grinding or rock drilling may be occurring elsewhere.

    **Traffic noise is almost always line source noise.** The standard attenuation rate for point source noise is 6 dBA, and the standard attenuation rate for line source noise is 3 dBA. These standard attenuation rates do not take into account any reduction factors, such as soft site, vegetation, or atmospheric conditions.

- ***Example** – All work on the project will occur at one location, and is considered point source noise. Therefore, adding the reduction for soft site conditions, construction noise will attenuate at a rate of 7.5 dBA per doubling of distance. Traffic noise (line source) will attenuate at a rate of 4.5 dBA per doubling of distance. This attenuation rate includes the 1.5 dBA reduction for soft site conditions.*

6. **Develop an attenuation table or use the equations for solving distances.** One way to compare traffic noise attenuation, construction noise attenuation, and background sound level is to construct a table. Using the predicted levels for each of these parameters, an attenuation table should display associated distance and decibel level. In noise assessments, 50 feet is the standard distance used to describe reference sound levels. Therefore, the initial distance for known or predicted levels is 50 feet. The extent of noise from construction activity is defined as the limit where noise from construction equipment is indistinguishable from noise or sound generated by the baseline conditions, either background (such as roadway traffic0 or ambient conditions, whichever is loudest. An attenuation table thus defines the first estimate of the extent of project-related noise.

   - ***Example using an attenuation table** – Project-related noise is estimated at 84 dBA, and traffic noise is estimated at 66 dBA with 40 dBA for ambient sound. Table 7-8 was generated using the predicted construction noise and traffic noise levels and the attenuation rates for each. In this example project, it would be safe to define the extent of project-related noise between 1,600 and 3,200 feet, because the table shows that this distance is where BOTH construction noise and traffic noise have attenuated to the ambient level (40 dBA).Therefore, at 3,200 feet, construction noise and traffic noise are not distinguishable from ambient sound level.*

   - ***Example with equations for solving for distance** – Project-related noise is estimated at 84 dBA, traffic noise is estimated at 66 dBA, and 40 dBA is estimated for ambient sound level. Using the equation in Section 7.1.4.2 the distance construction noise attenuated to ambient levels was to 2,877 feet. Using the equation in Section 7.1.4.2 for a line source noise, the distance traffic noise attenuated to ambient levels was 2,685 feet. In this example project, the extent of project-related noise is 2,877 feet. This is only slightly farther than traffic noise extends before attenuating to ambient levels (40 dBA). Therefore, at approximately 2,700 feet, traffic noise is not distinguishable from ambient sound levels and at approximately 2,900 feet construction noise is not distinguishable* *from ambient sound levels. Therefore. the extent of project generated noise is approximately 2,900 feet.*

- *If, in the example, traffic noise was high enough to extend past 2,900 feet, then the extent of project generated noise would be to where construction noise and traffic noise attenuated to the same level, but was still above the overall ambient level.*

**Table 7-8. Example noise attenuation table.**

| Distance from Roadway (ft) | Construction Noise (–7.5 dBA) | Traffic Noise (–4.5 dBA) | Existing Ambient Sound |
|---|---|---|---|
| 50 | 84 dBA | 66 dBA | 40 dBA |
| 100 | 76.5 dBA | 61.5 dBA | 40 dBA |
| 200 | 69 dBA | 57 dBA | 40 dBA |
| 400 | 61.5 dBA | 52.5 dBA | 40 dBA |
| 800 | 54 dBA | 48 dBA | 40 dBA |
| 1,600 | 46.5 dBA | 43.5 dBA | 40 dBA |
| 3,200 | 39 dBA | 39 dBA | 40 dBA |
| 6,400 | 31.5 dBA | 34.5 dBA | 40 dBA |

Between 1,600 and 3,200 feet, traffic attenuates to ambient levels.

If the project occurs in a developed area, where other background sound exceeds traffic noise, the biologist can also use known background sound levels associated with the level of development, and determine when construction noise drops below the development level to identify the extent of project-related noise.

The distance calculated using the noise assessment method described above is a worst-case scenario and does not take into account naturally occurring ambient sounds such as water and wind, or topography, which can physically block noise.

Examples of two projects that might warrant a more detailed noise assessment are provided below, along with the subsequent extent of noise impacts that was calculated for each.

The first example is a blasting project. If blasting occurs along a small portion of the project corridor where work would occur, it would be most effective to develop a composite noise assessment with one element that evaluated noise generated by blasting activities and a second element that evaluated noise generated by other construction activities. This would require the biologist to complete at least two noise assessments to effectively characterize these different elements. The area influenced by blasting noise would be substantially larger than the area affected by routine construction activities and equipment. Therefore, a larger radius would define the extent of noise surrounding the blasting activities than the radius defining the extent of noise from other activities. As a result, the noise component of the action area defined for the project would display a larger circle of anticipated noise effects around blasting activities than is exhibited around the remaining corridor.

A second example of a project requiring a more detailed noise assessment is a project corridor that is surrounded by both hard and soft site conditions. For those areas surrounding the road that possess soft site characteristics, the biologist would calculate the extent of noise that is generated by proposed construction activities and equipment using an attenuation rate for soft site conditions. For those areas surrounding the road that possess hard site characteristics, the biologist would calculate the extent of noise that is generated by proposed construction activities and equipment using an attenuation rate for hard site conditions. The extent of anticipated noise impacts in soft site areas would be smaller in area than the extent that is exhibited in hard site areas. As a result, the noise component of the action area defined for the project would display a larger radius of anticipated noise effects in hard site areas than is exhibited around the remaining soft site segments of the project corridor.

There may be some specific projects that warrant a more rigorous noise assessment than is described in the procedure or outlined in the examples provided above. For example, the blasting activities described above could take place in a canyon, where surrounding topography would inhibit the transmission of noise to surrounding areas or confine noise impacts to a smaller area. For these projects, the WSDOT project manager may request that a project biologist work with WSDOT noise specialists to develop a more sophisticated analysis. Figure 7-1 below illustrates the variation in the extent of noise impacts stemming from different project activities (paving vs. blasting) as well as variation in surrounding topography.

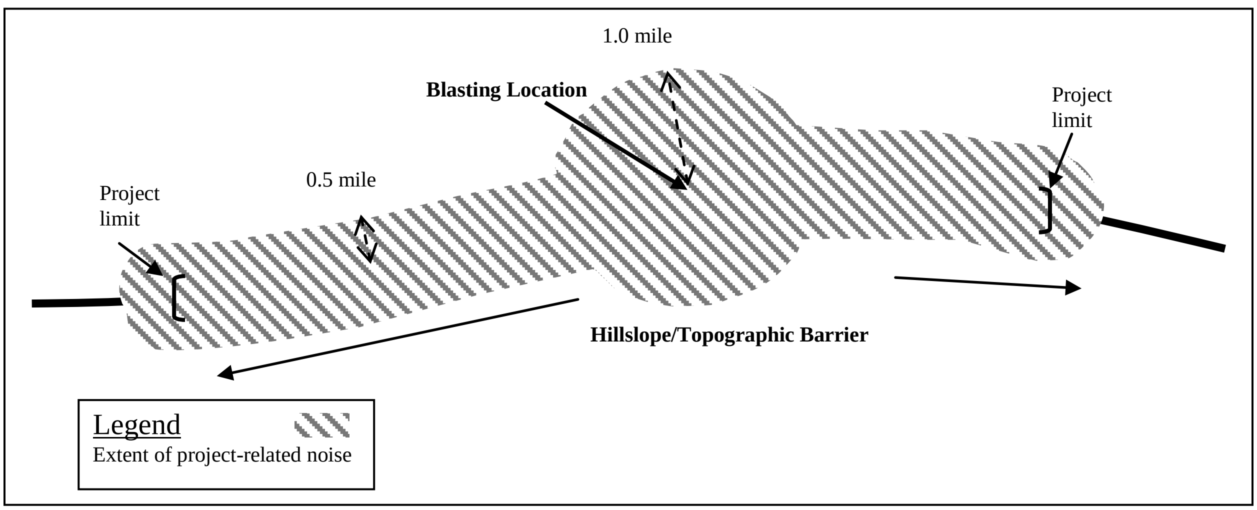



**Figure 7-1. Extent of noise based on project activities and topography.**

### 7.1.5 Species and Noise

So far, this discussion has focused on noise dynamics, generation, and prediction. The ability to identify and measure the extent of noise is only part of the assessment. The project biologist is also tasked with addressing the effects of noise on the species addressed in the BA.

### *7.1.5.1 How Animals Hear*

Many animals hear sounds with frequencies above and/or below the range of human hearing. Some animals have ears that move and which are shaped to help localize the direction from which noise originates. Much is not known, but it is assumed that animals in general have better hearing than humans.

Not all animals respond the same way to similar sound sources, and not all individuals respond the same way within a species. Animal response to sound depends on a number of complicated factors, including noise level and frequency, distance and event duration, equipment type and condition, frequency of noisy events over time, slope, topography, weather conditions, previous exposure to similar noises, hearing sensitivity, reproductive status, time of day, behavior during the noise event, and the animals location relative to the noise source (Delaney and Grubb 2003).

Different species exhibit different hearing ranges, so appropriate noise metrics and frequency ratings should be used when possible. For in-depth noise studies and hearing assessments, noise must be measured in a way that meaningfully correlates with the target species response. In this assessment, all decibel levels have been given as frequency weighted to approximate the way that humans hear. A-weighting (dBA) deemphasizes the upper and lower portions of the frequency spectrum, while emphasizing the middle portion of the spectrum (where humans have the greatest sensitivity). An audiogram (Figure 7-2) provides examples of the hearing range sensitivity for different species.

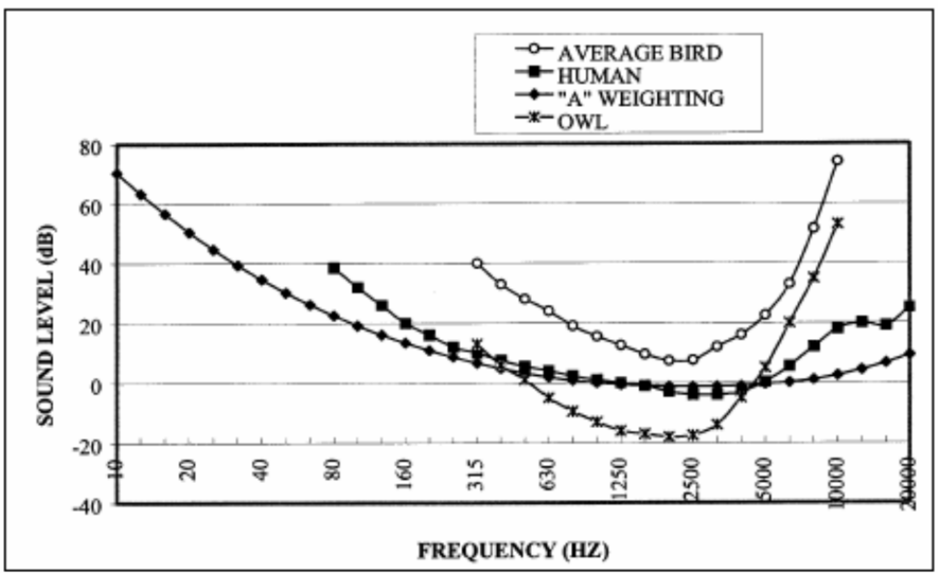



**Figure 7-2. Example audiograms.**
*Source: Pater et al. (1999).*

Notice how owls have better hearing than humans since they can detect noises in the same frequency range at lower decibel levels. An owl-weighted curve therefore emphasizes the middle frequency range where owls have the highest hearing sensitivity. The information presented in this discussion only uses A-weighted noise as a predictive factor. However, known threshold distances may provide the best available science source for understanding noise effects on species.

### 7.1.5.2 Threshold Distances and Effect Determinations

Threshold distances are defined as a known distance where noise at a given level elicits some response from a target species. This response can be visual, as in head-turning or flushing from a nest, or the animal may show little reaction. Particularly in birds, little or no reaction does not mean that no effect has occurred.

The U.S. Fish and Wildlife Service (USFWS) has provided WSDOT a copy of its biological opinion (BO) for the Olympic National Forest program of activities (USDI 2003). The USFWS updated Appendix 1 of the BO in September 2004. Appendix 1 provides estimates of noise levels at which incidental take of marbled murrelets and northern spotted owls is expected to occur due to harassment from noise-generating activities. The BO establishes harassment/injury levels for noise-generating activities specific to marbled murrelets and northern spotted owls.

It is important to note that the BO was provided as guidance from USFWS and is only applicable for use in certain situations because it was developed for a specific program of activity. The thresholds and effect distances were determined after factoring a suite of conservation measures specific to the project as defined by the Forest Service. Also, the analysis was specific to the habitat types found on the Olympic Peninsula. Lastly, the equipment types used by the Forest Service are often of a different type and caliber from those used on most transportation projects.

The threshold levels described in the BO can be used as a tool to assist the biologist in certain situations in making effect determinations for marbled murrelets and northern spotted owl. By using the information above to identify the project-related noise extent, the biologist can determine the distance at which the established threshold levels are located in relation to suitable habitat or documented species.

Harassment distance is the distance from an activity at which incidental take occurs due to disturbance. Within the BO, harassment distances and effect determinations for activities including but not limited to blasting, pile driving[2], and heavy equipment operation are defined (see Chapter 13 for effect determination guidance). In a previous BO for the Olympic National Forest, the USFWS used a standard 0.25-mile distance from most noise generating activities. In this BO, threshold distances in most cases are reduced significantly, based on the noise assessment provided in Appendix 1 of the BO.

The analysis determined noise levels at a distance by using a 7.5 dBA doubling distance reduction from noise-generating activities. They estimated the noise-only harassment/injury threshold for murrelets and owls is approximately 92 dBA at nest sites. This level does not

[2]. It is important to note that the pile sizes and types analyzed in the Forest Service opinion are not similar to those used on most transportation projects. In many cases they were evaluating the use of small-diameter and/or wood piles.

change throughout the analysis. Disturbance thresholds were estimated at 70 dBA, and detectability thresholds were estimated at 44 dBA. For the biologist's purpose, this threshold level applies in similar settings to that found in the Olympic National Forest – generally undeveloped, high precipitation, forested areas. The disturbance and detectability thresholds can vary, depending on the background sound level. The process that was used to determine the noise-only detectability, alert, disturbance, and harassment/injury threshold distances is outlined below:

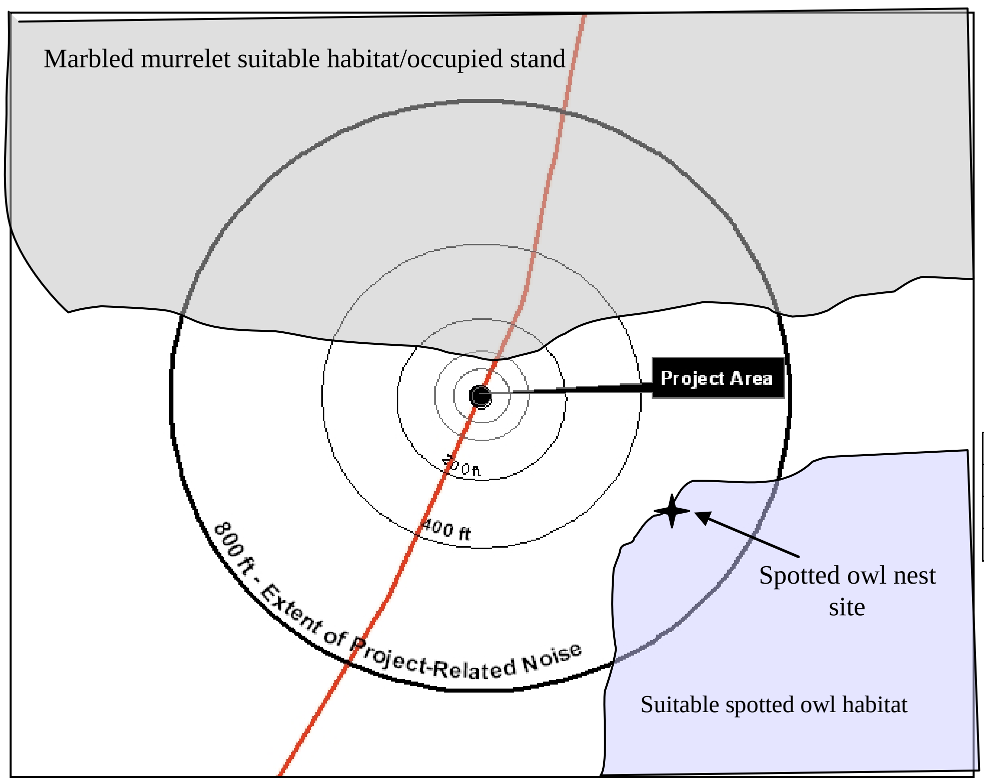
- ***Noise-only detectability threshold*** (where the noise is detectable, but a murrelet or spotted owl does not show any reaction). The detectability threshold was identified as being 4 dB above the baseline sound level. For example, in the Olympic National Forest biological opinion, baseline sound levels were identified at 40 dBA; therefore the detectability threshold was 44 dBA. This number varies based on baseline sound levels. Dooling and Hulse (1989) noted that 16 species of birds showed an average sensitivity of 4 dBA to detect a noise (USDI 2003).
- ***Noise-only alert and disturbance thresholds*** (alert is where the murrelet or spotted owl shows apparent interest by turning the head or extending the neck; disturbance is where the murrelet or spotted owl show avoidance of the noise by hiding, defending itself, moving the wings or body, or postponing a feeding). These threshold levels could not be documented with any precision, so they were subjectively placed between the detectability threshold and the harassment/injury threshold. The alert threshold is 57 dBA and the disturbance threshold is defined as 70 dBA (both $L_{max}$ metrics). These thresholds will change depending on the baseline sound level and do not widely apply.
- ***Noise-only harassment/injury threshold*** (where the murrelet or spotted owl is actually injured, defined as an adult flushed from the nest or the young missing a feeding). This distance was estimated using known data from several studies that documented noise-only flushes for several bird species. Based on the results of the studies, the noise-only harassment/injury threshold is 92 dBA ($L_{max}$ based upon maximum decibel levels reported in Canter 1997 as cited in USDI 2003). The detectability, alert, and disturbance threshold will differ as baseline sound differs, but this 92 dBA level remains constant.

### *7.1.5.3 Extent of Project-Related Noise versus Effects to Species*

One of the biggest mistakes made in writing a BA is to define the action area in terms of the extent of impacts on species rather than the zone of impact for the physical, chemical, and biological effects of the action.

To illustrate the concept of the project-related noise extent versus impacts on species, this section combines the noise analysis information from Section 7.1 through Section 7.1.4.1 with the thresholds used in the Forest Service's BO level information, to determine the effects on species and reach an effect determination.

In Figure 7-3, the project area is the dot in the center of the figure. The concentric circles show the noise attenuation distances for construction and traffic noise. The two small tables with the figure show the noise levels and distances from the example for construction and traffic noise attenuation. Also displayed are a spotted owl nest site and suitable habitat, and marbled murrelet suitable habitat identified as an occupied stand. These locations are placed only for the purposes of the example.




| Construction dBA | |
|---|---|
| 200 feet | 83 dBA |
| 400 feet | 75.5 dBA |
| 800 feet | 68 dBA |

| Traffic dBA | |
|---|---|
| 200 feet | 77 dBA |
| 400 feet | 72.5 dBA |
| 800 feet | 68 dBA |

**Figure 7-3. Example project area and species occurrence.**

The extent of project-related noise was determined to be 800 feet. This distance is shown in these figures as the heavier line. For this example, assume that noise is the farthest-reaching impact from construction activities; therefore, this distance represents the project action area.

- **Northern spotted owl –** The spotted owl nest site is located about 600 feet from the project area. Based on the example model above and using the equation for solving for construction noise level at a specific distance, the predicted decibel level from project-related noise at the nest is about 71 dBA and traffic related noise is about 70 dBA. The construction noise is above the somewhat arbitrary disturbance threshold of (70 dBA), and below the harassment/injury threshold of 92 dBA. However, at 600 feet from the project area, owls would be exposed to background sound levels from traffic at about 70 dBA. Because the detectability threshold is 4 dBA above background, spotted owls at the = nest site would not be able to detect noise levels below 74 dBA. Therefore, even though the nest is located in a zone where an owl could hear and show disturbance from the noise in the absence of traffic, project-related noise is unlikely to be detected at the nest and; therefore, noise disturbance from construction activities is not expected to delay a feeding attempt or cause avoidance behavior, and will not reach the level of causing harassment or injury (92 dBA) as defined in the Forest Service's BO. This project example also assumes that the nest is not in line-of-sight of construction activities. The project biologist should always address the potential for visual disturbance as well.

- **Marbled murrelet –** Suitable murrelet habitat exists about 80 feet from construction activity. In the absence of a survey to protocol, the project biologist must assume that suitable habitat is occupied habitat. By the time noise from construction enters suitable murrelet habitat, levels have attenuated to 93 dBA. This level is above the harassment/injury threshold of 92 dBA as defined in the Forest Service's BO. At this point, noise levels in suitable habitat would be high enough for harassment or injury to occur to any marbled murrelets potentially using the habitat, and an adverse impact would be expected.

## 7.2 Underwater Noise

In-water work activities contribute to noise in the marine and freshwater environments. Underwater noise from pile driving activities is an issue of concern for both NOAA Fisheries and the U.S. Fish and Wildlife Service (referred to here as the Services). Recent fish kills that resulted from in-water pile driving activities in Puget Sound, San Francisco Bay, and British Columbia, Canada, raised the Services' level of concern.

Noise behaves in much the same way in air as it does in water. The information and concepts presented here apply to both fresh and saltwater environments. Water currents bend noise waves upward when propagated into the current and downward downstream when observed over long distances. Noise waves bend towards colder denser water. Bottom topography and underwater structures can block, reflect, or diffract noise waves.

Underwater noise levels are measured with a hydrophone, or underwater microphone, which converts noise pressure to voltage, which is then converted back to pressure, expressed in

Pascals (Pa), pounds per square inch (psi), or decibels (dB).[3] The current standard distance for measuring source noise levels is 10 meters from the source, where the source and receiver are within line of sight of each other. As a general guideline, noise levels measured more than approximately 50 meters from the source may result in far field effects. Far field effects may result in calculations of a higher noise level at the receiver than would be measured in real time. Conversely, measurements taken too close to the source may result in near field effects (Laughlin 2008), which may also result in inaccurate noise level calculations at the receiver.

New guidance from NOAA (2012) states that if the primary intent of this measurement is to serve as a close-range datum with which to estimate sound pressure at much longer ranges through use of propagation modeling, then the range for this close-range datum should be not less than 3 H, where H is water depth.

Noise levels measured in air are typically used to assess impacts on humans and thus decibels are weighted (dBA) to correspond to the same frequency range that humans hear. Noise levels underwater are not weighted (dB) and thus measure the entire frequency range of interest, which may extend below and above the audible range of many organisms.

Several descriptors are used to describe underwater noise. Two common descriptors are the instantaneous peak sound pressure level ($dB_{peak}$) and the Root Mean Square ($dB_{RMS}$) pressure level during the impulse, sometimes referred to as the peak and RMS level respectively. The peak pressure is the instantaneous maximum overpressure or underpressure observed during each pulse and can be presented in Pascals (Pa) or SPL in decibels (dB) referenced to a pressure of 1 micropascal (dB re: 1 μPa). The RMS level is the square root of the energy divided by the impulse duration. This level is the mean square pressure level of the pulse. It has been used by NMFS to describe disturbance-related effects (i.e., harassment) to marine mammals from underwater impulse-type noises. When evaluating potential injury impacts to fish, peak sound pressure ($dB_{peak}$) is often used.

It is not possible to convert peak levels to RMS levels directly, but a conservative rule of thumb can be applied in noise assessments. Peak levels are generally 10 to 20 dB higher than RMS levels. To convert from peak to RMS, subtract 10 dB. This likely overestimates the RMS value, but enables the assessment to remain as conservative as possible. Likewise, to convert from RMS to peak, add 20 dB. This again may overestimate the actual peak noise level, but will provide a conservative estimate.

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[3]. Measurements are typically recorded electronically for analysis later. Pascals, or psi, can easily be converted to decibels (dB). To convert sound pressure energy to dB in air or water we use the same formula:

$$dB = 20 \log(p/pref)$$

Where dB is decibels, p is the pressure in micropascals (pascal multiplied by $10^6$), pref is a reference pressure. When converting air pressure levels a reference pressure of 20 micropascals is used. The 20 micropascal reference for sound in human studies was selected because it is near the threshold of hearing at 1kHz for the average young person. When converting underwater pressure levels a somewhat arbitrary reference pressure of 1 micropascal is used. Thus in many reports in the literature, underwater decibels are reported as decibels re: 1 micropascal, indicating that the decibels are referenced to 1 micropascal. All underwater sound pressure levels given in this chapter are in decibels (dB) referenced to 1 micropascal (μPa).

Sound Exposure Level (SEL) is often used as a metric for acoustic events and is often used as an indication of the energy dose. SEL is calculated by summing the cumulative pressure squared ($p^2$), integrating over time, and normalizing to 1 second. This metric accounts for both negative and positive pressures because $p^2$ is positive for both and both are treated equally in the cumulative sum of $p^2$ (Hastings and Popper, 2005). The units for SEL are dB re: 1 $\mu Pa^2$ sec.

### 7.2.1 Noise Generation, Transmission, and Reduction

Transmission loss (TL) underwater is the accumulated decrease in acoustic intensity as an acoustic pressure wave propagates outwards from a source. The intensity of the source is reduced with increasing distance due to spreading. Spreading can be categorized into two models, spherical spreading and cylindrical spreading models.

#### *7.2.1.1 Transmission Loss Calculations for Underwater Noise Levels*

Spherical (free-field) spreading occurs when the source is free to expand with no refraction or reflection from boundaries (e.g., the sediment or water surface). The TL for spherical spreading is defined by the formula:

$$\mathbf{TL = 20\ log(R)}$$

where R is the range or distance from the source. Spherical spreading results in a general 6 dB decrease in the intensity of the noise per doubling of distance.

Cylindrical spreading applies when noise energy spreads outwards in a cylindrical fashion bounded by the sediment and water surface. Cylindrical spreading is defined by the formula:

$$\mathbf{TL = 10\ log(R)}$$

This results generally in 3 dB per doubling of distance transmission loss of underwater noise. However, many construction projects produce noise in shallow water, and reflections from the sediment or water surface can reduce spreading considerably. Because of the complexity of these reflections it is difficult to define TL. Since noise energy is not perfectly contained by reflection and refraction most experts agree that the true spreading is often somewhere between 3 and 6 dB per doubling of distance, or approximately 4.5 dB per doubling of distance (Vagle 2003).

Currently, the Services use the practical spreading loss calculation as described by Davidson (2004) and Thomsen et al. (2006), where:

$$\mathbf{TL = 15Log(R_1/R_2)}$$

Where:

- R1 is the range or distance at which transmission loss is estimated.
- R2 is the range or distance of the known or measured sound level

Conversely the distance to where the source sound level drops off to some pre-determined sound level (e.g., the background sound level) can be calculated by rearranging the terms in the equation above giving:

$$\mathbf{R_1 = R_{2*}10^{(TL/15)}}$$

Where:

- TL = the difference between the source sound level and the background or other sound level at some distance.

This calculation assumes that noise energy decreases at a rate of 4.5 dB per doubling of distance, which is in between the spherical (6 dB) and cylindrical (3 dB) calculation. The complete equation for transmission loss includes a linear term in addition to the geometric term. A complete transmission loss equation might look like:

$$\mathbf{TL = 15\ log(R_1/R_2) + \alpha R}$$

Where:

- $\alpha$R is the linear absorption and scattering loss.

The linear term will have a greater influence on transmission loss 1,000 meters beyond the source. There is not common agreement on what should be used for the alpha term in the equation above, particularly for shallow water environments. Therefore, the linear term should be ignored for the present time until a decision can be made on the appropriate value to be used for alpha.

Illingworth and Rodkin (pers. comm. 2003) state that the underlying characteristic of transmission loss for pile driving in marine environments is spherical spreading; however, like propagation in air, a number of other factors, such as temperature gradients and currents, modify this characteristic. The common occurrence of decreasing temperature with depth can create significant shadow zones (noise refracts or bends towards the colder deeper water as it does in air) where the SPL can be as much as 30 dB lower than that from spherical spreading. In shallow water (less than 200 meters depth), reflections from the surface and bottom combine in such a way that the noise level TL, transitions from spherical spreading of 6 dB per doubling of distance to cylindrical spreading of 3 dB per doubling of distance at approximately 3H where H is the water depth (Dahl, pers. Comm. 2011). Thus, underwater noise propagation is highly variable. Monitoring data from some pile driving projects indicate that the actual spreading loss is intermediate between cylindrical and spherical spreading (Reyff 2003; Thomsen et al. 2006) while other data indicates that the actual spreading loss is closer to spherical spreading (Laughlin 2010a[4], 2010b[5]). Therefore, until a better spreading model can be developed and agreed on a

[4] Laughlin, Jim. 2010a. Underwater sound levels associated with driving steel piles at the Vashon ferry terminal. WSDOT Report.

[5] Laughlin, Jim. 2010b. Vashon Ferry Terminal Test Pile Project – Vibratory Pile Monitoring Technical Memorandum. WSDOT – Tech Memo.

practical spreading model, as described by Davidson (2004) and Thomsen et al. (2006) is most appropriate.

#### *7.2.1.2 Noise Reduction Factors*

*Hydrographic Conditions that Affect Noise Transmission*

In a current or strong tidal flux, noise propagated into the current would be refracted toward the surface where it would be quickly attenuated. However, this would depend on the velocity of the current and would occur on a scale of several hundred feet or more. This has not been researched adequately to make definitive determinations.

The water depth in which frequencies propagate must be greater than one-quarter the wavelength or $h = \lambda/4$ where h = water depth and $\lambda$ = wavelength (Urick 1983). Wavelength is determined by $\lambda = c/f$ where f = frequency in Hz and c = speed of noise in water (approximately 5,000 feet/sec). Since the dominant frequencies generated in pile driving are between 50 and 1,000 Hz, most of the energy is not propagated in water depths of 0.4 meters (1.3 feet) or less. However, some noise propagates through the sediment, especially the harder sediments, such as clay and rock, escaping into the water column somewhere else (albeit at a lower level than the source) through *sound flanking*.[6] Sound flanking is a common occurrence and has been observed by Burgess and Blackwell (2003) and WSDOT (2004d).

*Bottom Topography*

The method of determining how noise spreads as it moves away from the source can be difficult and site specific. It is dependent on sediment types, bottom topography, structures in the water, slope of bottom, temperature gradients, currents, and wave height. In the Puget Sound region, generally the sediments are relatively soft and the bottom slopes away from the shore relatively quickly. Depending on location and season, there can also be a relatively strong tidal flux in Puget Sound. Therefore, it is clear that general conclusions about spreading cannot be drawn without the likelihood of violating some of the site-specific assumptions listed above.

*River Sinuosity*

Noise propagation in rivers is limited by the sinuosity of a system. For example, where a river bends, noise is unlikely to propagate. A line-of-sight rule, meaning that noise may propagate into any area that is within line-of-sight of the noise source, is used to determine the extent of noise propagation in river systems.

[6]. *Sound flanking* refers to paths by which sound travels around an element, such as in water surrounding a piling. For example, a sound generated by pile driving can be flanked to another location by the ocean floor if the substrate is relatively uniform and uninterrupted from one location to another.

### 7.2.2 Baseline Underwater Sound Conditions

Existing underwater sound levels can serve as a baseline from which to measure potential disturbance impacts associated with project activities. Both ambient or natural noise sources and mechanical or human generated background sound contribute to the baseline sound conditions of a project site.

#### *7.2.2.1 Ambient or Background Sound Levels*

There are numerous contributing sources to background marine sound conditions. Sound levels produced by natural sources include snapping shrimp (71 dB) (Urick 1983), lightning strikes (260 dB), waves breaking, and rain on the ocean surface. Sound levels produced by human or mechanical sources include large tankers and naval ship engines (up to 198 dB) and 180+ dB for depth sounders (CRS Report 95-603 1995; Heathershaw et al. 2001). Commercial sonar devices operate in a frequency range of 15 kHz to 200 kHz and in an acoustical range of 150 to 215 dB (Stocker 2002). These levels are maximum source levels.

At the Bainbridge Island Ferry Terminal, underwater background sound levels were recorded as 151 dB peak (150 dB to 160 dB peak with construction equipment) (Laughlin 2005a[7]), but the Friday Harbor Ferry Terminal was between 131 dB to 136 dB peak (133 dB to 140 dB peak with construction equipment) (Laughlin 2005b[8]). In the vicinity of the Mukilteo Ferry Terminal, broadband background was recorded as 136 $dB_{RMS}$ to 137 $dB_{RMS}$ (Laughlin 2007[9]). Background levels were recorded north of the Mukilteo ferry terminal using high sensitivity hydrophones to be 135 $dB_{RMS}$ at the 90th percentile level and 124 $dB_{RMS}$ at the 50th percentile level (McGillivray et al. 2007[10]). Broadband background sound levels in Hood Canal (near the now decommissioned WSF Lofall-Southpoint ferry terminal) vary between 115 $dB_{RMS}$ and 135 $dB_{RMS}$ (Carlson et al. 2005)[11] . In a study conducted in Haro Strait, San Juan Islands, data showed that the broadband ambient half-hourly SPL in Haro Strait ranged from 95 dB to 130 dB (Veirs and Veirs 2005).[12] This same study indicated that 2-second SPL averages are lowest in

[7] Laughlin, J. 2005a. Underwater sound levels associated with pile driving at the Bainbridge Island Ferry Terminal Preservation Project. Prepared by Washington State Department of Transportation, Office of Air Quality and Noise, Seattle, WA. November 2005.

[8] Laughlin, J. 2005b. Underwater sound levels associated with restoration of the Friday Harbor Ferry Terminal. Prepared by Washington State Department of Transportation, Office of Air Quality and Noise, Seattle, WA. May 2005.

[9] Laughlin, J. 2007. Underwater sound levels associated with driving steel and concrete piles near the Mukilteo Ferry Terminal. Prepared by Washington State Department of Transportation, Office of Air Quality and Noise, Seattle, WA. March 2007.

[10] MacGillivray, A., Ziegler, E. and Laughlin, J. 2007. Underwater Acoustic Measurements from Washington State Ferries 2006 Mukilteo Ferry Terminal Test Pile Project. Technical Report prepared by JASCO Research, Ltd. for Washington State Ferries and Washington State Department of Transportation, 27 pp.

[11] Carlson, T.J., D.A. Woodruff, G.E. Johnson, N.P. Kohn, G.R. Plosky, M.A. Weiland, J.A. Southard, and S.L. Southard. 2005. Hydroacoustic Measurements During Pile Driving at the Hood Canal Bridge, September through November, 2004. Battelle Marine Sciences Laboratory, Sequim, Washington.

[12] Veirs, V.R. and S.R. Veirs. 2005, in preparation. Measuring orca call intensity with a shallow coastal fixed array.

the winter, slightly higher during summer nights, and highest during summer days as a result of small boat traffic.

Broadband background sound levels in Puget Sound in the nearshore areas (i.e., within 1 kilometer of shoreline with frequent human activities and shipping or ferry lanes) are approximately 135 $dB_{RMS}$. Background measurements from human activities collected beyond this distance in the San Juan Islands indicate that 120 $dB_{RMS}$ is the approximate broadband ambient sound level. WSDOT has recently acquired hydrophones for determining background sound levels at Washington State ferry terminals and in the vicinity of other WSDOT facilities. Data collected as part of this effort will help to more accurately characterize background conditions throughout the Puget Sound region. Recently, WSDOT analyzed broadband background sound (20 Hz to 20 kHz) over three consecutive 24-hour periods at Mukilteo, Port Townsend, Anacortes, Edmonds, and Seattle. The decibels reported for these locations represent 50 percent of the cumulative distribution functions of these three periods, including both daytime and nighttime sound levels. Based on this recent research, the broadband sound level at Mukilteo is 123 dB, at Port Townsend is 104 dB, at Anacortes is 130 dB, at Edmonds is 123 dB, and at Seattle is 128 dB (NMFS 2011). For projects occurring in the vicinity of any of these locations, these background sound levels should be assumed.

Background sound levels in deep freshwater lakes or deep slow moving rivers are approximately 135 $dB_{RMS}$, similar to marine levels near developed shorelines. In shallow (1 foot deep or less), fast moving rivers, the ambient sound levels are louder due to the water moving over rocks and boulders and the wave action at the surface. Background levels are estimated at 140 $dB_{RMS}$ in these systems (Laughlin 2005).

For areas where site-specific sound data is not available, NOAA has developed guidance for collecting background sound data for use in marine mammal consultations and permit applications. This guidance is available on the web at: <http://www.nwr.noaa.gov/Marine-Mammals/MM-sound-areas.cfm>. In the absence of background sound data, the acoustic effect thresholds established by NOAA Fisheries staff, and described in section 7.2.4.4 *Threshold Levels*, should be used to define areas of potential sound effects for marine mammal consultations and permitting efforts.

### 7.2.3 Underwater Construction Noise

Although there are many sources of noise in the underwater environment, the most common sources of noise associated with construction activities are impact hammers. Underwater noise from pile driving is generated using different types and diameters of piles, types of hammers, and by driving the piles into different types of substrates. Each configuration can produce different noise levels and waveform characteristics.

Noise generated by impact pile driving is impulsive in nature. Impulsive noises have short duration and consist of a broad range of frequencies. Impulsive waveforms are characterized by a rapid pressure rise time (the time in milliseconds it takes the wave form to rise from 10 percent to 90 percent of its highest peak) that occurs within the first few milliseconds followed by rapid fluctuation (underpressure and overpressure) about the ambient pressure.[13] Although other methods such as peak-to-peak or zero-to-peak are used by some researchers to define rise time the method of calculating rise time noted above has become the standard for pile driving waveforms. Although there is no definitive correlation between rise time and injury to fish it is thought that a rapid rise time may cause injury.

This section provides general information regarding potential sound levels and characteristics associated with various equipment and pile types. NOAA has developed guidance for more accurately characterizing and collecting source sound data from impact and vibratory pile driving, for use in marine mammal consultations and permit applications. This guidance is available on the web at: <http://www.nwr.noaa.gov/Marine-Mammals/MM-sound-areas.cfm>.

#### *7.2.3.1 Pile Installation Equipment*

There are five pile-driving hammer types that are commonly used. Vibratory hammer, diesel hammer, air or steam hammer, hydraulic hammer, and drop hammer used for smaller timber piles. Wave forms generated by each of these hammer types are described below.

Vibratory hammers vibrate the pile into the sediment by use of an oscillating hammer placed on top of the pile. The vibratory action causes the sediment immediately surrounding the pile to liquefy and the pile can be driven through the sediment. In some cases piles can be driven by vibratory hammers to a depth where they can reach load bearing capacity, but the bearing capacity must be tested with the use of an impact hammer. This is referred to as proofing. To proof a pile it is struck with an impact hammer until the bearing capacity can be measured. This may take just a few strikes or several strikes depending on site-specific characteristics.

Peak noise levels can exceed 180 dB; however, the rise time is relatively slow (Figure 7-4). Vibratory driving noise levels are generally 10 to 20 dB lower than impact hammer driving. Vibratory installation of steel piles in a river in California resulted in sound pressure levels that were not measurable above the background noise created by the current (Reyff 2006).

Impacts on fishes or other aquatic organisms have not been observed in association with vibratory hammers. This may be due to the slower rise time and the fact that the energy produced is spread out over the time it takes to drive the pile. As such, vibratory driving of piles is generally considered less harmful to aquatic organisms and is the preferred method.

[13] The total duration of the impulse varies based on several factors, which include the force applied to the pile, the nature of the pile (i.e., wood, concrete, or steel as well as diameter) and the substrate into which the pile is being driven. In general, most of the energy associated with each impulse occurs within the first 30 to 50 milliseconds. Recent measurements of underwater sound generated by impact pile driving have shown that most of the energy is contained in a frequency range between approximately 25Hz and 1.6 kHz. Within this frequency band the highest energy densities are found between 50 and 350 Hz (Reyff et al. 2002).

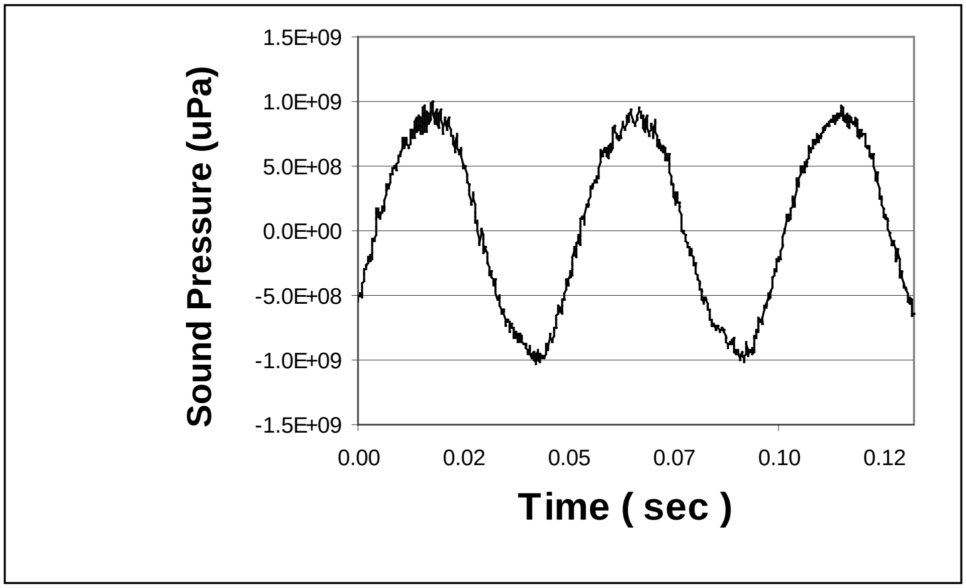


**Figure 7-4. Typical vibratory hammer wave form.**

Air or steam-driven impact hammers use air to lift a heavy piston and then use gravity to drop the piston onto the top of the pile. The height of the piston can be varied to allow more potential energy to transfer to the piston and then transfer as kinetic energy into the pile. Air hammers produce underwater noise waveforms with each pile strike that are similar to diesel hammers (Figure 7-5). Therefore, noise levels and rise time are similar for air hammers and diesel hammers.

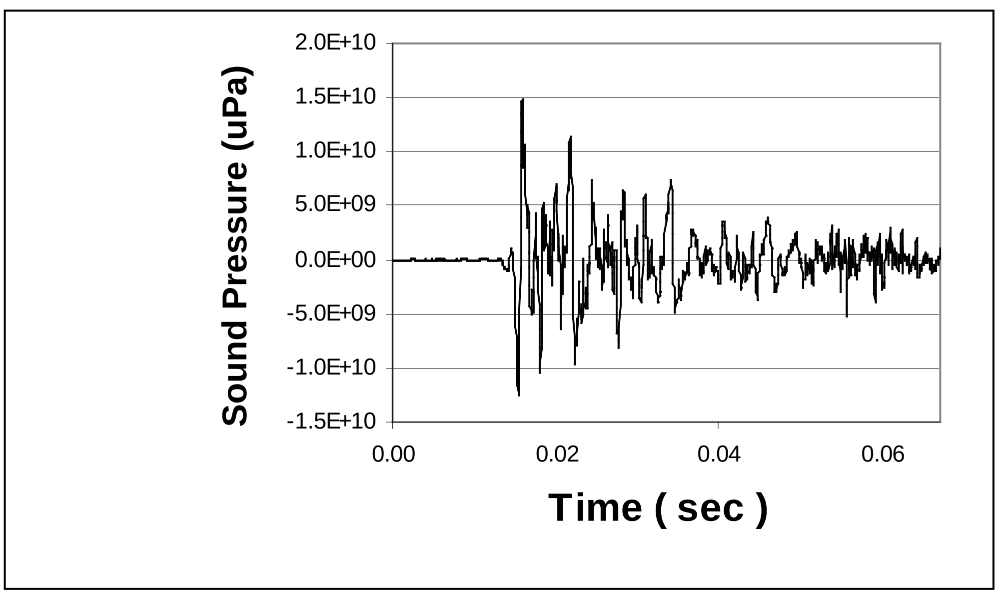


**Figure 7-5. Typical air hammer wave form for a single pile strike.**

Diesel-driven impact hammers ignite diesel fuel to lift a heavy piston and then use gravity to drop the piston onto the top of the pile. The height of the piston can be varied somewhat by varying the amount of diesel fuel going into the combustion chamber. Diesel hammers produce underwater noise waveforms with each pile strike that are similar to air hammers (Figure 7-6).

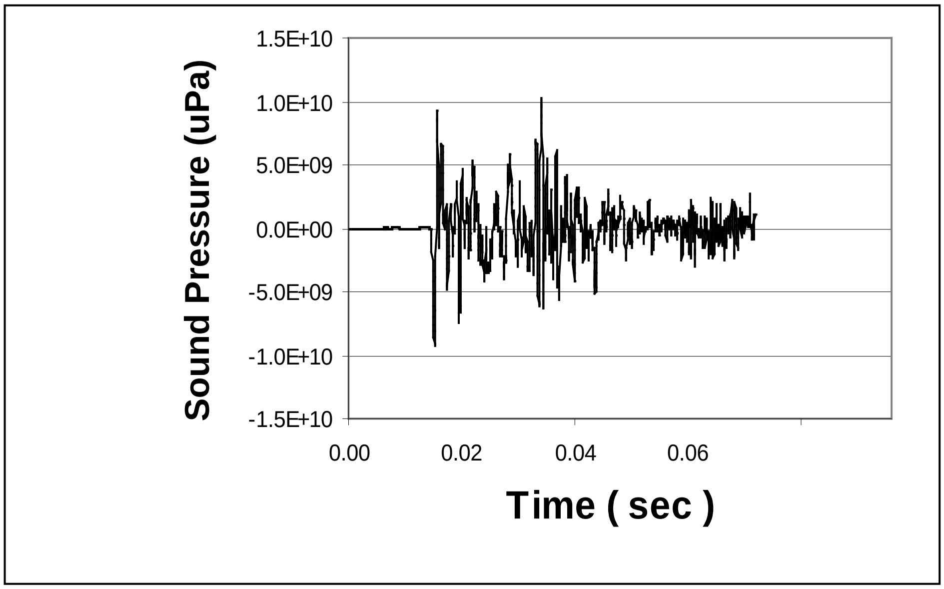


**Figure 7-6. Typical diesel hammer wave form for a single pile strike.**

Hydraulic driven impact hammers use hydraulics to lift a heavy piston and then use gravity to drop the piston onto the top of the pile. In addition, with some hydraulic hammers, hydraulic pressure is used to drive the hammer into the pile instead of using gravity. Hydraulic hammers produce a somewhat different waveform signature with a much more rapid rise time (Figure 7-7). The diesel hammer is the recommended hammer to use based on rise time data gathered from the Friday Harbor Ferry Terminal Study.

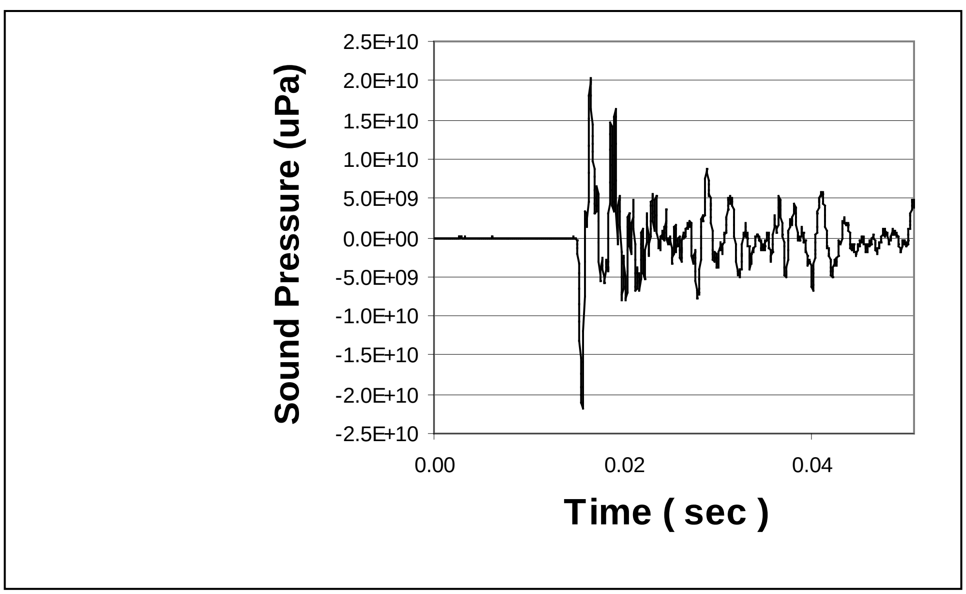


**Figure 7-7. Typical hydraulic hammer wave form for a single pile strike.**

### *7.2.3.2 Different Pile Types*

The size and type of pile also affect the sound generated by pile-driving activities. There are three types of piles typically used in transportation projects: timber, concrete, and steel. Sound pressure levels associated with each of these types of piles are summarized in Table 7-9. Sound levels from projects within Washington State are used when available. The sound levels are denoted as either peak, RMS, or SEL; and all are unattenuated values and measured at 10 meters from the pile unless otherwise noted.

Other considerations include:

- Peak levels are generally 10 to 15 dB higher than RMS levels.
- Peak pressures occur between 1 millisecond (msec) very close to the pile and 5 to 6 msec after the strike at a distance of 20 meters from the pile.
- The greater the pile surface exposed under the water, the more acoustic energy radiates. Shallower water (e.g., water less than about 2 feet deep) does not propagate noise energy effectively, especially at lower frequencies (Urick 1983).

### *7.2.3.3 Noise Reduction Strategies*

Various measures have been developed to reduce underwater noise generated by pile driving. These include air bubble curtains (confined or unconfined), temporary noise attenuation piles, air filled fabric barriers, and isolated piles or cofferdams. An air bubble curtain is a device used during pile driving that infuses the area surrounding piles with air, thereby generating a bubble screen. The purpose is to reduce peak underwater sound pressure levels (SPLs), thereby reducing potential adverse effects to aquatic organisms.

The components of a bubble curtain typically include a high volume air compressor, primary and secondary feed lines, and air distribution manifolds. Longmuir and Lively (2001) recommended that manifolds should have 1/16-inch air release holes every 3/4-inch along their entire length (Figure 7-8). The Services currently recommend basing bubble curtain design on that described in Longmuir and Lively (2001). The air distribution manifolds are placed surrounding the piling below the water surface where the pile meets the sediment. An effective bubble curtain system should distribute air bubbles that completely surround the perimeter of a pile to the full depth of the water column. Maintaining the optimal size of the bubbles, based on their resonant frequency, greatly enhances the noise attenuation of the bubble curtain (Vagle 2003).

In areas where currents exist, where the seafloor or substrate is not level, or piles are being driven at an angle other than 90 degrees to the water surface, the size or number of manifolds should increase to provide coverage throughout the water column. In some of these cases, particularly where currents can move the curtain away from the pile, unconfined bubble curtains may prove ineffective, and a confined system may be required.

**Table 7-9. Sound pressure levels associated with pile types.**

| Pile Type | Sound Level (single strike) | | |
|---|---|---|---|
| Wood piles:[14] | 180 $dB_{peak}$ | 170 $dB_{RMS}$ | 160 dB SEL |
| Concrete piles:[15] | 192 $dB_{peak}$ | 176 $dB_{RMS}$ | 174 dB SEL |
| Steel H-piles[16]: | 190 $dB_{peak}$ | 175 $dB_{RMS}$ | 155 dB SEL |
| 12-inch steel piles: | 208 $dB_{peak}$[17] | 191 $dB_{RMS}$[18] | 175 dB SEL[19] |
| 14-inch steel piles: | 198 $dB_{peak}$ @ 22 m[20] | 182 $dB_{RMS}$ @ 22 m[18] | 170 dB SEL @ 22m |
| 16-inch steel piles[21]: | 200 $dB_{peak}$@ 9 m | 187 $dB_{RMS}$ @ 9 m | |
| 24-inch steel piles[22]: | 212 $dB_{peak}$ | 189 $dB_{RMS}$ | 181 dB SEL |
| 30-inch steel piles[23]: | 212 $dB_{peak}$ | 195 $dB_{RMS}$ | 186 dB SEL |
| 36-inch steel piles[24]: | 214 $dB_{peak}$ | 201 $dB_{RMS}$ | 186 dB SEL |
| 60-inch dia. steel piles[25]: | 210 $dB_{peak}$ | 195 $dB_{RMS}$ | 185 dB SEL |
| 66-inch dia. steel piles[25]: | 210 $dB_{peak}$ | 195 $dB_{RMS}$ | |
| 72-inch dia.steel pile[18] | 214 $dB_{peak}$ | 189 $dB_{RMS}$ | 182 dB SEL |
| 96-inch dia. steel piles[18] | 220 $dB_{peak}$ | 205 $dB_{RMS}$ | 195 dB SEL |
| 126-inch dia. steel piles[25]: | 213 $dB_{peak}$ @ 11 m | 202 $dB_{RMS}$ @ 11 m | |
| 150-inch dia. steel piles[26]: | 200 $dB_{peak}$ @ 100 m | 185 $dB_{RMS}$ @ 100 m | |

[14]. Timber piles, 12-inches in diameter, have been measured underwater by Illingworth and Rodkin and are published in the draft Pile Driving Compendium which as of the date of this update has not yet been released as final. Illingworth and Rodkin (2004) have compared the shape of the sound wave between steel piles and timber piles and found that a timber pile produced a more 'rounded' wave than a steel pile. This means that although the peak sound levels may be similar, the waveform appears more stretched out for a timber pile than for a steel pile and the rise time is relatively slower. A slower rise time means that the shock wave produced with each pile strike is not as severe presumably resulting in less damage to the fish. The effect is similar to the difference between a push and a punch.

[15]. Concrete piles measured had 36-inch diameter and 4 –inch wall thickness (~419 lbs/ft weight per unit length (MacGillivray et al. 2007). Concrete 24-inch diameter piles have been measured by POV, and sound levels range between 190 dBpeak and 205 dBpeak (DesJardin 2003 pers. comm..). While there have been no documented fish kills with the installation of concrete piles, the Services may require sound mitigation strategies or monitoring because of the lack of formally documented effects (CalTrans 2003 personal communication).

[16]. Illingworth and Rodkin, pers. comm. (2004). Illingworth and Rodkin (2004 personal communication) measured 10-inch steel H-piles in a slough approximately 6 feet deep at 10 meter distance from the pile to range between 180 – 195 dB (160-177 dB RMS). They also measured 10-inch steel H-pile at Noyo Bridge with peak levels at 180 dB (165 dB RMS) at 30 meters from the pile. An H-pile driven on shore next to the water produced peak levels in the water of 170-175 dB (155-162 dB RMS) at 23 meters from the pile. The measurements at Noyo Bridge were highly variable due to the shallow water.

[17]. Illingworth and Rodkin (2002).

[18]. CalTrans. 2009. Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish.

[19] Laughlin (2006).

[20].Reyff (2003).

[21].Laughlin, Jim. 2004. Underwater Sound Levels Associated with the Construction of the SR 240 Bridge on the Yakima River at Richland. WSDOT, Office of Air Quality and Noise, Seattle, WA. September 2004. 33 pages.

[22].Laughlin (2005a).

[23].Laughlin (2005b).

[24].Laughlin (2007).

[25].Reyff (2003).

[26].Laughlin, Jim. 2011. Underwater sound levels associated with driving 72-inch steel piles at the SR 529 Ebey Slough Bridge Replacement Project. WSDOT, Office of Air Quality and Noise, Seattle, WA.

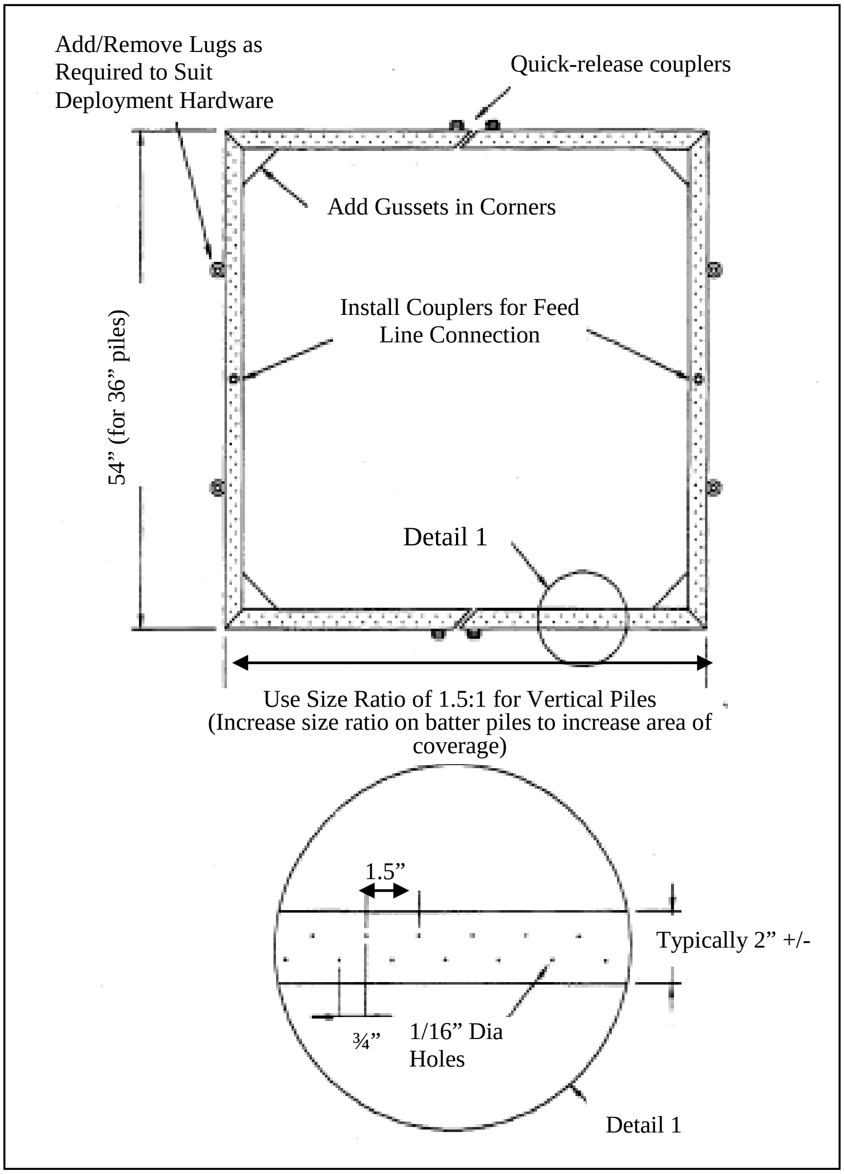


**Figure 7-8. Air manifold design.**
Source: Longmuir et al. (2001).

Proper design and implementation are key factors in bubble curtain effectiveness for reducing SPL. Studies on the effectiveness of bubble curtains for reducing noise pressure waves have found varied results. MacGilivray et al. (2007) and Reyff (2003) reviewed previous reports, and also conducted a study on the use of bubble curtains and their reduction of noise pressure waves. In previous studies, Reyff (2003) found that bubble curtains resulted in a 0 to 10 dB reduction in RMS. While monitoring pile driving of three large piles (inside diameter of 8 feet, outside diameter of 8.5 feet), bubble curtains reduced peak pressures from 6 to over 20 dB and RMS values from 3 to 10 dB. Thorson and Reyff (2004) found similar results with a reduction of from 5 to 20 dB in peak SPLs. Vagle (2003) studied the underwater effects of pile driving at four locations in Canada. This study reported reductions of between 18 dB and 30 dB when using a properly designed bubble curtain.

Reyff et al. (2002) evaluated the effectiveness of an isolated pile (IP) technique using a confined bubble curtain system. The IP was 3.8 meters in diameter with the interior coated with 2.54 centimeter closed cell foam. In this type of bubble curtain system, the IP surrounds the actual driven pile, and contains the bubble flow. The IP and bubble curtain system provided a dramatic reduction in both peak pressures and RMS levels. Peak pressures were reduced by 23 to 24 dB and RMS levels were reduced by 22 to 28 dB. Most of the reduction in noise energy occurred at frequencies above 100 Hz.

WSDOT conducted a test pile project for the Vashon Ferry Terminal (Laughlin, 2010a) where the University of Washington Applied Physics Lab and Department of Mechanical Engineering tested a Temporary Noise Attenuation Pile (TNAP) which consisted of an inner and outer steel casing with an inner air chamber between the casings that was partially filled with foam. At the bottom on the inside of the inner casing was a bubble ring. Sound reduction achieved ranged between 8 and 14 dB with an overall average of 11 dB. Most of the reduction in noise energy occurred at frequencies above approximately 800 Hz.

Fabric barriers have also been used to attenuate SPLs from pile driving activities. The theory is somewhat the same as for an air bubble curtain, in that the goal is to change the local impedance of the water that noise must travel through. Cofferdams can be used as well, and may be applied either full of water or drained to the mudline. Cofferdams full of water provide only limited attenuation, while dewatered cofferdams may provide the best isolation of the driven pile.[27]

WSDOT monitoring has revealed significant variability in the attenuation achieved by different projects and also between different attenuation devices. The results of this research are depicted in Tables 7.10 and 7.11 below.

**Table 7.10. Range, mean, and standard deviations for sound attenuation rates achieved on WSDOT projects.**

| Location | Range (dB) | Mean (dB) | Standard Deviation (dB) |
|---|---|---|---|
| Friday Harbor | 0-5 | 2 | 2.2 |
| Bainbridge Island | 3-14 | 7 | 4.7 |
| Cape Disappointment | 6-17 | 11 | 4.9 |
| Mukilteo | 7-22 | 15 | 10.6 |
| Anacortes | 3-11 | 8 | 3.1 |
| SR 520 | 3-32 | 20 | 11.1 |
| SR 529 | 16-26 | 22 | 4.3 |

[27]. Thorson, P. and J.A. Reyff. 2004. Marine mammal and acoustic monitoring for the eastbound structure. San Fransisco – Oakland Bay Bridge East Span Seismic Safety Project. Report submitted for Incidental Harassment Authorization issued November 14, 2003, to Caltrans.

**Table 7.11. Range, mean, and standard deviations for different sound attenuation technologies.**

| Attenuation Technology | Range (dB) | Mean (dB) | Standard Deviation (dB) |
|---|---|---|---|
| Unconfined Bubble Curtain | 0-32 | 11.9 | 8.7 |
| Confined Bubble Curtain | 0-38 | 12.1 | 13.8 |
| DNAP/TNAP | 7-21 | 12/7 | 4.4 |

Tables 7-12 through 7-14 show the noise reductions achieved for various WSDOT projects, pile diameters, substrate types, and hammer energy ratings since 2005.

Recent research has demonstrated that sound pressure waves generated by impact pile driving will travel down the pile, enter the substrate and then travel back up and out of the substrate at a different angle, entering the water column outside of the bubble curtain (Reinhall and Dahl 2011). These sound pressure waves will not be attenuated and are a major factor in some of the variability observed in the effectiveness of the bubble curtains. Because of the large variability in the effectiveness of bubble curtains (and fabric barriers), there is no standard rate of attenuation assumed. Projects may either state their expectation of bubble curtain performance for use in the analysis, taking into consideration the variability described above, or a rate of effectiveness may be determined through the consultation itself. If the BA states an expected performance level (thereby making that level part of the project description), the author should coordinate with WSDOT acoustics experts to determine a realistic performance standard for the specific project given the proposed attenuation technology and site conditions. If the level of attenuation that is assumed during the consultation is not achieved by the project, the project may be required to shut down until re-initiation of consultation is complete. It is therefore critical to assume a level of attenuation that is attainable.

### 7.2.4 Determining the Extent of Underwater Project-Related Noise

The action area for a project is defined as the extent of the physical, chemical, and biological effects of the action. When considering the extent of the noise element of the action area (i.e., extent of project-related noise), consider the underwater area through which noise will travel until it reaches ambient levels.

This section provides instruction on how to estimate the extent of underwater project-related noise to determine a component of a project's action area and to ascertain potential effects to listed species, relative to established biological thresholds for disturbance and injury. NOAA has developed guidance for estimating sound propagation for pile driving sounds relevant to marine mammals. This guidance is available on the web at: <http://www.nwr.noaa.gov/Marine-Mammals/MM-sound-areas.cfm>.

**Table 7-12. Noise reduction values for all Washington State DOE projects from 2005 to 2009 for steel piles of different diameters using an unconfined bubble curtain.**

| Location | Pile Diameter (inches) | Substrate Type | Hammer Energy Rating (ft-lbs) [a] | Date | Pile # | Average Noise Reduction per Pile (dB) |
|---|---|---|---|---|---|---|
| Friday Harbor Ferry Terminal | 24 | Silty sand with hard clay layer | 60,000 | 2/10/05 | 1 | 5 |
| | | | | 2/23/05 | 4 | 0 |
| | | | | 2/24/05 | 5 | 1 |
| | 30 | Silty sand with hard clay layer | 60,000 | 3/4/05 | 8 | 3 |
| Bainbridge Island Ferry Terminal | 24 | Sand and Fist-sized rocks to 1-foot rocks | 55,000 | 10/18/05 | 1 | 14 |
| | | | | | 2 | 10 |
| | | | | 10/20/05 | 3 | 7 |
| | | | | | 4 | 3 |
| | | | | | 5 | 3 |
| Cape Disappointment Boat Launch Facility [b] | 12 | Silt and mud with glacial till layer | 52,000 | 12/13/05 | 1 | 6 |
| | | | | 12/14/05 | 2 | 14 |
| | | | | | 3 | 11 |
| | | | | | 4 | 17 |
| | | | | | 5 | 6 |
| Mukilteo Test Pile Project | 36 | Sand and silt | 164,000 | 11/16/06 | R2 | 7 |
| | | | | | T2 | 22 |
| Anacortes Ferry Terminal | 36 | Sand and Silt Mix | 165,000 | 1/17/07 | 1 | 11 |
| | | | | | 2 | 11 |
| | | | | 1/19/07 | 4 | 5 |
| | | | | | 5 | 10 |
| | | | | | 6 | 8 |
| | | | | | 7 | 3 |
| | | | | | 8 | 9 |
| SR 520 Test Pile Project | 24 | Very loose unconsolidated silt overlying glacial till | 20,100 | 10/27/09 | PB-1 | 11 |
| | | | | | PB-2 | 3 |
| | | | | | PB-3 | 26 |
| | | | | | PB-4 | 28 |
| | 30 | | | 10/29/09 | WAB2 | 32 |
| | | | | | WAB5 | 19 |

**Table 7-12 (continued). Noise reduction values for all Washington State DOE projects from 2005 to 2009 for steel piles of different diameters using an <u>unconfined</u> bubble curtain.**

| Location | Pile Diameter (inches) | Substrate Type | Hammer Energy Rating (ft-lbs) [1] | Date | Pile # | Average Noise Reduction per Pile (dB) |
|---|---|---|---|---|---|---|
| SR 529 Ebey Slough Bridge Replacement Project | 72 | Deep loamy silt | 327,222 | 1/6/11 | 4 | 16 |
| | | | | | 5 | 22 |
| | | | | 1/11/11 | 3 | 24 |
| | | | | | 6 | 26 |
| | | | | | : | |
| : | | | | | | |

[a] Actual energy used during operation of impact hammer is approximately 50% to 70% of this maximum energy for most piles. All hammers are diesel.

[b] These piles had steel wings that linked the piles together and pile caps were used between the pile and the hammer which possibly increased the number of total strikes per pile.

**Table 7-13. Noise reduction values for all Washington State DOT projects from 2005 to 2009 for steel piles of different diameters using a <u>confined</u> bubble curtain.**

| Location | Pile Diameter (inches) | Substrate Type | Hammer Energy Rating (ft-lbs) | Date | Pile # | Average Noise Reduction per Pile (dB) |
|---|---|---|---|---|---|---|
| SR 24 – Yakima River | 24 | Large 1-to 3-foot diameter boulders (riprap) with river rock and gravel below | 60,000 | 6/7/05 | 3 | 0 |
| | | | | 6/14/05 | 5 | 5 |
| | | | | | : | |
| Eagle Harbor Maintenance Facility | 24 | unknown | 164,000 | 10/31/05 | 1 | 7 |
| | | | | | 3 | 4 |
| | | | | | | |
| SR 411 Cowlitz River | 24 | Silty Sand | 72,900 | 7 – 8/ 2006 | 4 | 8 |
| | | | | | 7 | 4 |
| | | | | | 8 | 9 |
| | | | | | | |
| SR 520 Test Pile Project | 30 | Very loose unconsolidated silt overlying glacial till | 20,100 | 10/29/09 | WAB1 | 38 |
| | | | | | WAB4 | 34 |
| | | | | | : | |
| | | | | | | |

[a] Actual energy used during operation of impact hammer is approximately 50% to 70% of this maximum energy for most piles. All hammers are diesel.

**Table 7-14. Noise reduction values for all Washington State DOT projects from 2006 to 2009 for steel piles of different diameters using a Temporary or Double Walled Noise Attenuation Pile (TNAP or DNAP).**

| Location | Pile Diameter (inches) | Substrate Type | Hammer Energy Rating (ft-lbs) [a] | Date | Pile # | Average Noise Reduction per Pile (dB) |
|---|---|---|---|---|---|---|
| Mukilteo Test Pile Project (TNAP1) [b] | 36 | Sand and silt | 164,000 | 11/16/06 | R4 | 7 |
| | | | | 2/19/07 | | 15 |
| Mukilteo Test Pile Project (TNAP2) [c] | 36 | Sand and silt | 164,000 | 11/16/06 | R3 | 21 |
| | | | | | R1 | 17 |
| SR 520 Test Pile Project (DNAP) [d] | 30 | Very loose unconsolidated silt overlying glacial till | 20,100 | 10/29/09 | WAB3 | 11 |
| Vashon Test Pile Project (modified TNAP) [e] | 30 | Silty Sand | 164,620 | 11/17/09 | P-14 | 9 |
| | | | | | P-10 | 9 |
| | | | | 11/18/09 | P-16 | 13 |
| | | | | | P-8 | 12 |

[a] Actual energy used during operation of hammer is approximately 50% to 70% of this maximum energy for most piles. All hammers are diesel.

[b] TNAP1 (Temporary Noise Attenuation Pile) is a hollow walled steel pile casing placed around the pile being driven. Hollow cavity accidentally filled with water during installation, thus substantially reducing its potential effectiveness. The TNAP1 was repaired and retested on 2/19/07.

[c] TNAP2 is a steel pile with a 2-inch thick closed cell foam lining on the inside of the pile and a perforated metal screen on the inside of the foam.

[d] DNAP is a steel casing with a 1-inch air space and 4 inches of insulation and an inner steel casing sealed together at the top and bottom.

[e] Modified TNAP is a hollow steel casing with a 2-inch foam-filled hollow wall and a bubble ring on the inside at the bottom but only sealed at the bottom.

#### *7.2.4.1 Steps for Defining the Extent of Project-Related Noise*

The following subsection provides instruction for determining the extent of project-related underwater noise to help define the action area; noting that noise is just one element of the project that must be considered when defining the action area.

A brief example of how one would use the concepts discussed above to define the extent of project-related underwater noise is provided here.

- Assume that a typical unattenuated peak noise level produced by driving a steel pile with a diesel hammer is 195 $dB_{RMS}$ at a distance of 10 meters (33 feet) from the pile. Also assume a log (R) coefficient of 4.5 dB per doubling of distance (practical spreading model).
- Calculations used by the Services for determining at what point the project noise becomes indistinguishable from ambient sound assume a 4.5 dB decrease with each doubling of distance. At this rate of loss, the noise level from the source described above declines to 135 $dB_{RMS}$ at 100,000 meters (62 miles). $R_1 = R_2 * 10^{((195-135)/15)}$. However, in both river systems and in Puget Sound, land masses are usually encountered well before this distance is reached, effectively reducing the extent of the action area. As mentioned above, temperature gradients, bottom topography, and currents can cause noise levels to attenuate more quickly. Therefore, it is often difficult to accurately determine the extent of noise using a standard geometric spreading model.
- In addition, the use of a bubble curtain can reduce the levels at the source. Assuming a 5 dB reduction at the source described above from use of an air bubble curtain, the distance at which the noise reaches an ambient level (135 $dB_{RMS}$) in marine waters is reduced to 46,416 meters, a 54 percent reduction of the noise extent.

The following example will use the Practical Spreading Loss model in use by the Services to illustrate the procedure for determining the extent of project-related noise.

1. **Estimate or measure the equipment noise level for the project**. Though there are many types of equipment potentially used during underwater construction, pile driving is one of the most common activities in underwater construction. To determine the noise levels associated with pile driving determine the hammer type as well as the pile type being used. Peak decibels associated with different types of piles are listed in Table 7-9 above.
   - ***Example** – Driving a 30-inch steel pile will produce a 196 $dB_{RMS}$ noise level estimated at 10 meters from the pile.*

2. **Estimate or measure the baseline sound level**. Determine if there have been any noise studies in the vicinity of your project that may be able to specifically define baseline underwater sound levels. If not, based on some of the information cited above, you could estimate a reasonable baseline sound level.

   - ***Example** – The project takes place in Puget Sound. Noise studies completed in the vicinity of the project determined a baseline broadband noise level of 135 $dB_{RMS}$.*

3. **Determine applicable noise reduction factors**. Identify if there are any noise reduction factors that are present either as a result of the physical location of the project (shallow water, confined harbor, soft-bottom substrates, structures, currents, etc.) or impact minimization measures that will be implemented during construction.

   - ***Example –** The project site is bordered on the east by shoreline and upland habitats. As a result, underwater noise associated with pile-driving activities will dissipate 100 to 200 meters to the east of the locations where piles will be installed. To the west shorelines are located 5 miles away. The northern end of the harbor is located 2 miles away and the southern end of the harbor is located 2 miles away from the project site. A bubble curtain will not be used.*

4. **Use the Practical Spreading loss model to determine the extent of project-related underwater noise.**

   - ***Example – TL = 15Log($R_1$/$R_2$), or solved for $R_1$, $R_1$ = ($10^{(TL/15)}$)($R_2$).** $R_1$ is the distance where noise attenuates to ambient levels, $R_2$ is the range of the known noise level, and TL is the amount of spreading loss (known noise level – ambient sound level). ($10^{(196-135/15)}$)(10) =116,591 meters. Therefore, according to the Practical Spreading Loss model, noise would not attenuate to ambient levels in open water for approximately 72 miles. This is likely an invalid distance, and true attenuation to ambient levels likely happens somewhere prior to the modeled distance. The project biologist should determine where an appropriate extent is located, based on land masses, marine objects, and variances in ambient conditions throughout the environment. For example, a busy shipping lane located near the area may limit the extent of noise.*

   - ***Figure 7-9 maps the extent of the example project.** Noise pressure travels in a linear direction (concentrically) away from the source; when the noise intersects a landmass, it is assumed to not travel* *through the land mass or to reflect off of the land mass. Any protruding land mass within the aquatic area, in this case the mouth of the harbor, will likely create a "shadowing effect". The actual extent of project-related noise defined by the Practical Spreading Loss model would actually be much further out than shown in the example. The opposite shoreline defines the extent.*

### *7.2.4.2 Species and Noise*

As is stated in the first section of this chapter, one task the project biologist must complete is identifying and measuring noise to determine the noise element of the action area. Another task the project biologist must complete is analyzing the effects of noise on the species that are addressed in the BA. Information and guidance to complete this task are provided in the sections below.

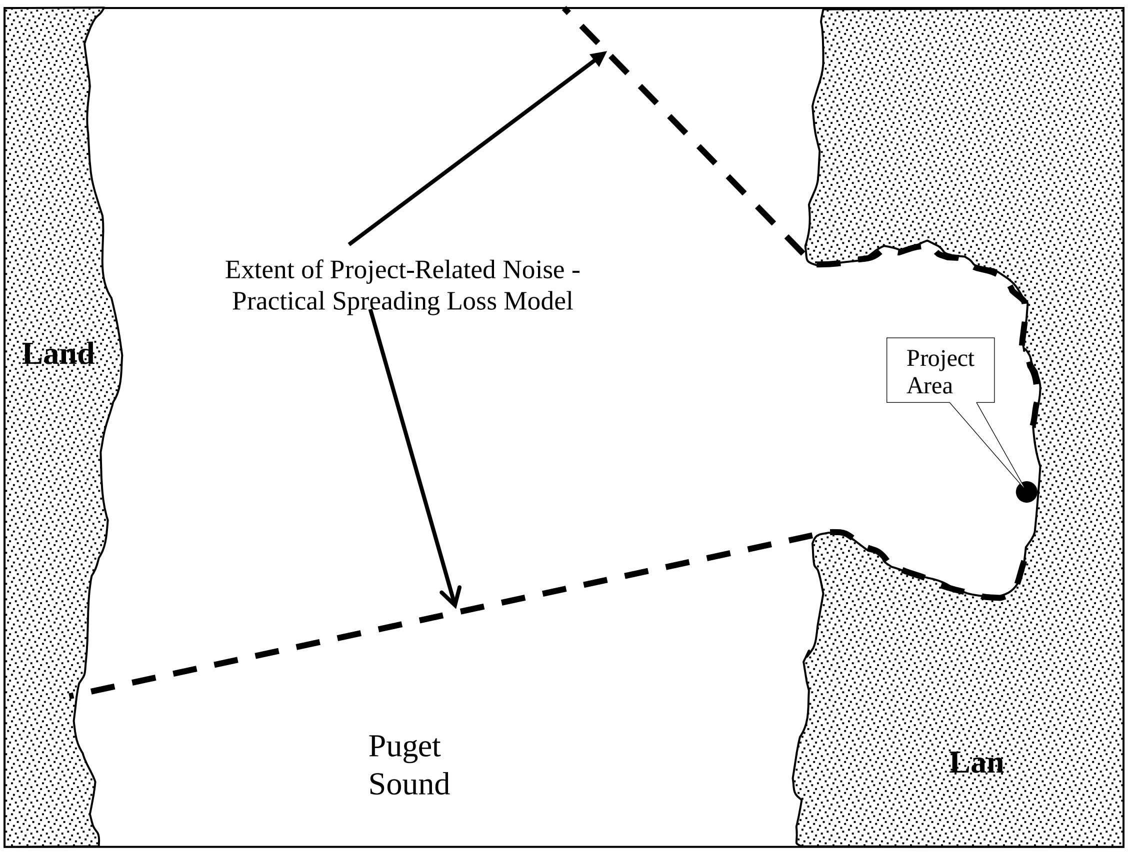


**Figure 7-9. Example showing extent of project-related noise.**

### *7.2.4.3 How Aquatic Species Hear*

*Fish – Hearing*

The main sensory organ in fish is the lateral-line system that detects low-frequency (<100 Hz) particle motion in water. The lateral-line organ is likely involved in acoustic repulsion when the source is within a few body lengths of the fish. The inner ear located within the skull of the fish is sensitive to vibration rather than noise pressure.[28] In fish species that are hearing specialists, the gas-filled swim bladder acts as a transducer that converts noise pressure waves to vibrations, allowing the fish to detect noise and vibration.

Fish species with no swim bladder or a small one tend to have a relatively low auditory sensitivity. Fish having a fully functional swim bladder tend to be more sensitive. Fish with a close coupling between the swim bladder and the inner ear are most sensitive.

Most audiograms of fishes indicate a low threshold (higher sensitivity) to noises within the 100 Hz to 2 kHz range (Stocker 2002) (Figure 7-12).[29] Anderson (1992) suggests that juvenile fish may have less developed hearing abilities so the distance at which they could detect pile driving noises might be much less than adults. Audiograms developed for various fish species are based on noise pressure. However, fish do not hear with noise pressure. They hear with particle motion. Therefore, the thresholds and frequency ranges listed above and in Figure 7-10 will likely be revised when those data are available.

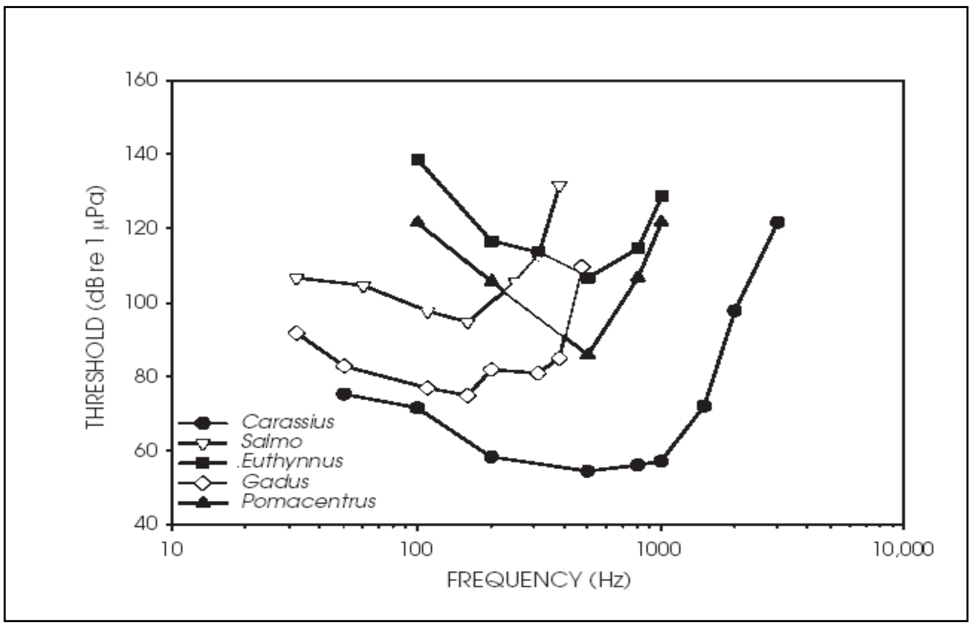


**Figure 7-10. Audiogram for several fish species.**
Source: Burgess and Blackwell (2003).

[28]. Fish have three symmetrically paired structures in the inner ear associated with bony otoliths: the lagena, sacculus, and utriculus. In most species, the saccule and lagena detect acoustic pressure and acoustic particle motion (Popper and Fay 1973) and the utricle is involved in sound detection by several species of clupeids and perhaps other species (Popper and Fay 1993).

[29]. Cod have a hearing threshold of 75-80 dBrms between 100 and 200 Hz (Chapman and Hawkins 1973). Atlantic salmon have a sensitivity of 95 to 100 dBrms between 100 and 200 Hz (Hawkins and Johnstone 1978). Since both species are most sensitive between 100 and 200 Hz one would expect to see damage to salmon occurring with exposure to continuous sound at about 200 dBrms (Hastings 2002).

High-intensity noises may temporarily or permanently damage the hearing of fish.[30] Temporary hearing damage is referred to as a temporary threshold shift and permanent hearing damage is referred to as a permanent threshold shift. However, damage to hearing by intense noise depends on auditory thresholds and will thus vary from species to species (Popper and Fay 1973, 1993).[31] Popper et al. (2005) exposed three species of fish to noises from a seismic airgun, having noises similar to pile driving. Peak noise levels ranged between 205 and 209 dB. They exposed a hearing generalist (broad whitefish), a hearing specialist (lake chub), and a species that is intermediate in hearing (northern pike). They found that the hearing generalist had no significant effects from air gun exposure; the lake chub indicated the most effect in temporary threshold shift, and the northern pike showed a significant hearing loss but less than that of the lake chub. Lake chub and northern pike returned to their respective normal thresholds after 18 to 24 hours.

One study completed by Feist et al. is particularly pertinent to species potentially occurring in Washington. Feist et al. (1992) looked at the effects of concrete pile driving activities on the behavior and distribution of juvenile pink and chum salmon in Puget Sound. The authors found that juvenile pink and chum salmon (1 to 2 inches total length) did not change their distance from shore or cease feeding in response to pile driving. However, they did find that there were substantial differences in the distributions and sizes of fish schools on pile-driving days versus non-pile-driving days.

### *Fish: Lethal Impacts Associated with Noise*

Risk of injury or mortality for aquatic species and fish associated with noise, in general, is related to the effects of rapid pressure changes, especially on gas filled spaces in the body. Rapid volume changes of the swim bladder may cause it to tear, reducing hearing sensitivity in some hearing specialist species, and loss of hydrostatic control.

[30]. Popper and Clarke (1976) found that goldfish (*Carassius auratus*) demonstrated up to a 30 dB decrease in hearing sensitivity when exposed to 149 dB for 4 hours, but hearing returned to normal after 24 hours. Enger (1981) used a sound level of 180 dB to destroy bundles of cilia on the saccular maculae of codfish as evidenced by scanning electron microscopy and assumed permanent hearing loss.

[31]. Enger (1981) exposed 26 cod (*Gadus morhua*) to continuous tones of 180 dBrms at frequencies from 50 to 400 Hz for 1 to 5 hours and found destruction of auditory cilia cells in the saccule. Hastings (1995) found destruction of auditory sensory cells when she and her colleagues exposed goldfish (*Carassius auratus*) to continuous tones of 189, 192, and 204 dBpeak at 250 Hz and found destruction of ciliary bundles correlate with sound pressure level at a 95% confidence level. Hastings et al. (1996) found destruction of sensory cells in the inner ears of Oscars (*Astronotus ocellatus*) four days after being exposed to continuous sound for 1 hour at 180 dBpeak and 300 Hz. Fish exposed to 180 dBpeak sounds at 60 Hz either continuous or 20% duty cycle (impulsive) or to 180 dBpeak sounds at 300 Hz and 20% duty cycle for 1 hour had no apparent damage. The authors also found no damage in fish allowed to survive for only 1 day after exposure, suggesting that damage may develop slowly.

Hastings et al. (1996) also examined the sensory cells of the lateral line and semicircular canals of the inner ear in the Oscars and found no damage. The authors speculated that this could be related to the fact that these sensory cilia cells do not have an overlying otolith.

McCauley et al. (2003) exposed caged pink snapper (*Pagrus auratus*) to air gun sound levels as the ship passed by the caged fish, producing damaged cilia cells that did not regenerate up to 58 days after exposure.

According to Hardyniec and Skeen (2005)[32] and Hastings and Popper (2005) the effects of underwater noises created by pile driving on fish may range from a brief acoustic annoyance to instantaneous lethal injury depending on many factors including:

- Size and force of the hammer
- Distance of the fish from the pile
- Depth of the water around the pile
- Depth of the fish in the water column
- Amount of air in the water
- The texture of the surface of the water (amount of waves on the water surface)
- The bottom substrate composition and texture
- Size of the fish
- Species of the fish
- Physical condition of the fish

Physostomus fishes, such as salmonids, regulate the air in their swim bladders through a direct connection to the esophagus. Salmonids acclimate their swim bladders by gulping air at the surface, and as they swim deeper the swim bladder becomes compressed. When exposed to a sudden positive pressure, or overpressure, the swim bladder compresses further. When exposed to a sudden negative pressure, or underpressure, the swim bladder may expand beyond its original volume at depth but may not suffer or injure any other organs because it has some room to expand. Physostomus fishes acclimated to the surface atmospheric pressure may suffer less injury or mortality the deeper they are in the water column, whereas those acclimated to deeper water pressure may suffer more injury near the surface or in shallow areas (Carlson 2003 personal communication).

Physoclistus fishes, such as bluegill, regulate air in the swim bladder through the circulatory system. In a physoclistus fish, the swim bladder will roughly maintain its volume at depth. During exposure to underpressure, the swim bladder will expand, possibly tearing and causing damage to other organs. The magnitude of the expansion of the swim bladder is dependent on the magnitude of the underpressure. It functions according to Boyle's law: The volume of a confined amount of gas at constant temperature is inversely proportional to the pressure applied to the gas (Carlson 2003 personal communication).

[32.] Hardyniec, Sara and Sarah Skeen. 2005. Pile driving and barotraumas effects. J. Transportation Research Board, No. 1941, pp. 184 – 190.

There have been a few studies addressing the effects of pile driving on fish, which are described here, and others are summarized in the footnotes.[33] Illingworth and Rodkin (2001) found that there was not only a relationship between distance from the pile but an increase in the degree of damage and number of fish impacted with increasing duration of exposure to pile-driving activities.[34] Illingworth and Rodkin (2001) found that both a smaller hammer size and bubble curtains reduced injuries to fish.[35] In the literature review by Hastings and Popper (2005) they found that the study by Yelverton (1975) using underwater explosives indicated that smaller fish were more likely to be harmed than larger fish during underwater explosions.

*Fish: Behavioral Impacts Associated with Noise*

Mueler et al. (1998)[36] and Knudsen et al. (1992; 1996)[37] found that juvenile salmonids (40 to 60 mm length) exhibit a startle response followed by a habituation to low frequency (infrasound) in the 7 to 14 Hz range. Mueler et al. (1998) and Knudsen et al. (1992, 1996) also indicate that noise intensity level must be 70 to 80 dB above the hearing threshold at 150 Hz to obtain a behavior response.

According to Feist et al. (1992) broad-band pulsed noise (e.g., pile driving noise) rather than continuous, pure tone noises are more effective at altering fish behavior. However, the noise

[33]. Diver observations made by the Port of Vancouver (PoV) in Canada following pile driving 36-inch steel piles into sandstone bedrock found higher mortality rates on the bottom than observed on the surface although no counts were reported (DesJardin 2003 personal communication). Fish mortalities at the PoV included herring, juvenile salmon, rockfish, and tomcod.

Experiments conducted by the Pacific Northwest National Laboratory (PNNL) placed bluegill in a hyperbaric chamber and acclimated one group to simulated ambient surface pressures of 101 kilopascals (kPa) and another group to simulating ambient pressures at 30 foot depth of 191 kPa inside a hyperbaric chamber. The fish were then exposed to 400 kPa for 30 to 60 seconds followed by rapidly decreased pressure to 2 and 10 kPa respectively within 0.1 seconds. The fish were then held for 48 hours for observation (Carlson 2003 personal communication). The results for bluegill indicated 90% injury and 21% mortality to the 30 foot acclimated group and 35% injury and 5% mortality to the surface acclimated group (after 48 hours). Carlson (2003 personal communication) found that both acclimation (Pa) and exposure (Pe) pressures are important and the ratio of Pe to Pa is an important predictor to mortality and possible injury. Similar unpublished work has been done with rainbow trout and results indicated no mortality and minimal injury.

[34]. In one experiment, all fish exposed to pile driving for one minute were unaffected while 80 percent of fish exposed for 6 minutes exhibited significant tissue damage. In a second experiment, only fish exposed for 40 minutes or longer were seriously injured.

[35]. The authors put fish in cages at various distances from 8-foot diameter steel piles, and 60% of fish were found with damage to their internal organs as far as 150 meters (492 feet) from the pile driven by the large hydraulic hammer (1,700 kJ maximum) and no bubble curtain. With a smaller hydraulic hammer (750 kJ maximum) and a bubble curtain in operation, only 40% were damaged at this distance. In general, the greatest impacts were observed within a 30-meter (98-foot) radius of the pile. It is assumed that there would be a decrease of 3 dB with halving of the hammer energy.

[36]. Mueller, R. P., D. A. Neitzel, W.V. Mavros, and T. J. Carlson. 1998. Evaluation of low and high frequency sound for enhancing fish screening facilities to protect outmigrating salmonids. U.S. Dept. of Energy, Portland, Oregon. Project number 86-118.

[37]. Knudsen F.R., P.S. Enger, and O. Sand. 1992. “Awareness reactions and avoidance responses to sound in juvenile Atlantic salmon, *Salmo salar L.*” *Journal of Fish Biology* 40:523-534.

Knudsen F.R., C. Schreck, and S. Knapp. 1996. “Avoidance responses and habituation to low frequency sound in juvenile steelhead and Chinook.” (Submitted for publication.)

level must be at least within the minimum audible field of the fish for the frequencies of interest (1 to 100 Hz for pile driving). Ambient sound should be at least 24 dB less than the minimum audible field of the fish, and the pile driving noise levels had to be 20 to 30 dB higher than ambient sound levels in order to produce a behavioral response (in herring) (Olsen 1969, 1971).

Behavioral sensitivity is lowest in flatfishes that have no swim bladder and also in salmonids (brown trout) in which the swim bladder is present but somewhat remote from the inner ear. Gadoid fishes (cod, whiting) in which the swim bladder is closely associated with the inner ear display a relatively high sensitivity to noise pressure (Turnpenny et al. 1994).

Hastings and Popper (2005) present a summary of different noise levels and effects on fish based on a review of the best available science from the literature that has the most relevance to pile driving. However, the review does not include Pacific Salmon species or bull trout, the species project biologists would need to address in their BAs.

Jorgensen (unpublished) from Fisheries and Oceans Canada recently presented preliminary data suggesting that that noise generated by an air gun at noise levels between 205 and 209 $dB_{peak}$ indicated no significant difference in startle response in the vertical direction or vertical velocity and a possible slight difference in the horizontal direction. The author also indicated that observed fish did not actively avoid the noise, and there appeared to be no hearing loss. The fishes studied included broad whitefish, northern pike, and lake chub.

*Hearing – Marine Mammals*

Different taxa of marine mammals are sensitive to different frequencies of sound. For small toothed whales (Odontocetes), such as killer whale, and pinnipeds (seal and sea lion) studies of hearing have generally been conducted on a few individuals of some species. Therefore, individual variation within a species may not be represented in the results. No studies of baleen whales (Mystecetes sp.) have been conducted.

Killer whales have an estimated auditory bandwidth of 1 kHz to 100 kHz and are most sensitive around 20 kHz (Szymanski et al. 1999, as cited in 76 FR 4300). In a review by Au and Hastings (2008)[38] the audiogram shape, level of maximum sensitivity, and high-frequency limits of the killer whale were similar to other small odontocetes tested.

Humpback whales, like all baleen whales, are low-frequency cetaceans. Because no direct measurements of auditory capacity have been conducted for these large whales, hearing sensitivity for low-frequency whales has been estimated by Southall et al. (2007) [39] from various studies or observations. A generalized estimate of an auditory bandwidth of 7 Hz to 22 kHz for all baleen whales is cited in Southall et al. (2007) from Ketten et al. 2007.

[38] Au, W.W. and M.C. Hastings. 2008. Principles of Marine Bioacoustics. Spring Science, LCC.

[39] Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Green Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquat. Mamm. 33:414-521.

Pinnipeds communicate both on land and underwater. Both in-air and in-water pinniped audiograms are similar to typical mammalian audiograms; there is a low-frequency region that increases in sensitivity with frequency, a high-sensitivity dip at mid frequencies, and a high-frequency region in which sensitivity decreases rapidly with frequency (Au and Hastings 2008). Underwater hearing studies have been conducted on several species of pinnipeds but not on Steller sea lions. Studies conducted on California sea lions (in the same family as Steller sea lions, Otariidae) found the range of maximal hearing sensitivity is between 1 and 28 kHz, functional high frequency hearing limits are between 35 and 40 kHz, with peak sensitivities from 15 to 30 kHz (Schusterman et al. 1972, as cited in 76 FR 4300). At lower frequencies (below 1 kHz) sounds must be louder in order to be heard (Au and Hastings 2008; Kastak and Schusterman 1998, as cited in 73 FR 41318). As previously stated, studies of hearing have generally been conducted on a few individuals. Therefore, individual variation within a species may not be represented in the results.

Southall et al. (2007) designated a functional hearing group for pinnipeds and estimated the lower and upper frequencies of the groups. The functional hearing group designated for all pinnipeds is 75 Hz and 75 kHz for underwater hearing (with the greatest sensitivity between approximately 700 Hz and 20 kHz) and between 75 Hz and 30 kHz for in-air hearing. Studies indicate that pinnipeds are sensitive to a broader range of sound frequencies in water than in air (Southall et al. 2007).

*Marine Mammals: Impacts Associated with Noise*

Marine mammals produce sounds in various contexts and use sound for various biological functions including social interactions, foraging, orientation, and predator detection. Interference with producing or receiving sounds could have negative consequences including impaired foraging efficiency from masking, altered movement of prey, increased energetic expenditures, and temporary or permanent hearing threshold shifts due to chronic stress from noise (Southall et al. 2007).

Marine mammals, like other mammals, can experience a masking effect from noise exposure. Masking occurs when environmental noise is loud enough to cover or mask other noises. However, unlike other mammals and pinnipeds, toothed whales echolocate and communicate by ultrasonic pulsed calls, whistles, and clicks. Their highly developed acoustic ability is used for navigation, prey location, and communication. Noise can mask echolocation and impede communication necessary for cooperative foraging (Bain and Dahlheim 1994) [40]. Masking decreases the area where prey items are detectable by echolocation. Masking is most acute when the noise source is directly in front of killer whales (Bain and Dahlheim 1994).

Exposure to chronic or high levels of sound may result in physiologic effects to hearing or, in extreme cases tissue damage or stranding. Temporary threshold shift (TTS) occurs when the

40 Bain, D.E., R. Williams, J.C. Smith, and D. Lusseau. 2006. Effects of vessels on behavior of Southern Resident killer whales (*Orcinus spp*.) 2003-2005. NMFS Contract AB133F05SE3965. Available from D.E. Bain, Friday Harbor Laboratories, University of Washington, 630 University Road, Friday Harbor, WA 98250.

auditory system is exposed to a high sound level over a duration that causes the cochlear cilia cells to fatigue and results in an a temporary decrease in hearing sensitivity. The hearing sensitivity returns when the cilia cells return to their normal shape (Au and Hastings 2008). Permanent threshold shift (PTS) is the term used when hearing sensitivity is permanently altered from high levels of sound exposure due to damage of the cochlear cilia cells. High levels of sound exposure may result in hemorrhaging around the brain and ear bones (NMFS 2005[41]). Other results from intense acoustic exposure, such as naval sonar, may lead to stranding of cetaceans, either from behavioral reactions or injury.

A sound source's frequency compared to a species hearing frequency range, as well as the intensity and energy from the source that are received by an animal, affect the potential for sound to cause masking, a behavioral response, or physical injury. In addition, Southall et al. (2007) noted, that even in well controlled studies, behavioral responses in marine mammals and conditions which elicit the response are highly variable and strongly dependent upon the context of exposure and by an individual subject's prior experience, motivation, and conditioning.

### *7.2.4.4 Threshold Levels*

In 2002, Hastings recommended 180 $dB_{peak}$ for injury and 150 $dB_{RMS}$ for behavior effects as the thresholds for protecting salmon.[42] These recommendations have been used by the Services in numerous biological opinions. Popper et al. (2006)[43] developed a more conservative interim criteria which proposes the use of both 187 dB SEL and 208 $dB_{peak}$ as protective thresholds of injury to fish (this does not address potential harassment, so does not replace the 150 $dB_{RMS}$ threshold for behavioral effects). The SEL is based on a single strike rather than on cumulative strikes. In January of 2008 Hastings and Popper proposed refining these injury thresholds to 189 dB SEL and 206 $dB_{peak}$. Based on recommendations of the Fisheries Hydroacoustic Work Group, in June of 2008, FHWA, WSDOT, the Oregon Department of Transportation, California Department of Transportation, Regions 1 and 8 of the USFWS, and the Northwest and Southwest Regions of NMFS reached agreement on the interim fish noise exposure thresholds.

The current interim thresholds for fish are as follows:

- 206 $dB_{peak}$
- 187 dB cumulative SEL for fish $\geq$ 2 grams
- 183 dB cumulative SEL for fish < 2 grams

41 NMFS. 2005. Assessment of acoustic exposures on marine mammals in conjunction with USS Shoup active sonar transmissions in the eastern Strait of Juan de Fuca and Haro Strait, Washington. 5, May 2003. NMFS Office of Protected Resources, Silver Spring, MD.

[42]. These recommendations were based on long-term exposure to a pure tone.

[43]. Popper, Arthur N., Thomas J. Carlson, Brandon L. Southall, and Roger L. Gentry. 2006. Interim Criteria for Injury of Fish Exposed to Pile Driving Operations: A White Paper.

Where cumulative SEL (SEL(cum)) is calculated as:

SEL(cum) = SEL(single strike at ~10 meters from the pile) + 10 * log (# strikes).

The number of strikes is estimated based on how many strikes occur in a summation period. Typically, the summation period is a day and includes a break in pile driving for 12 to 18 hours. The break between summation periods allows fish to move out of the affected areas or time to recover from temporary threshold shifts. If the cumulative SEL threshold is exceeded in a summation period, physical injury to fish is possible. Whether or not physical injury occurs is dependent on the project, and site-specific factors, such as local habitat conditions, as well as species specific factors. One factor to consider is whether the fish being analyzed are stationary or are migrating through an area. It is important to note that NMFS assumes that single strike SELs below 150 dB do not accumulate to cause injury.

The 150 $dB_{RMS}$ threshold for potential behavioral effects is still being applied; however, more research and discussions will be needed to get a better understanding of the behavioral component of the thresholds. It is impossible to mitigate pile driving noise levels below the 150 $dB_{RMS}$ level at this time. Sound pressure levels in excess of 150 $dB_{RMS}$ are expected to cause temporary behavioral changes, such as elicitation of a startle response, disruption of feeding, or avoidance of an area. Depending on site specific conditions, project timing, project duration, species life history and other factors, exposure to these levels may cause behavioral changes that rise to the level of “take”. Those levels are not expected to cause direct permanent injury, but may indirectly affect the individual (such as impairing predator detection). It is important to note that this is a “may affect” threshold, not an adverse affect threshold. Whether or not 150 $dB_{RMS}$ causes take is dependent on consideration of numerous factors.

WSDOT has observed fish kills during some of its pile driving. Sound level measurements at the Mukilteo Test Pile Project (Laughlin, 2007) indicated that the estimated sound levels measured at the time of the fish kills were 209 $dB_{peak}$, 202 $dB_{RMS}$, and 183 dB SEL for a single strike. Many of the killed fish observed were pile perch.

The USFWS (2004 and 2011) has also identified underwater threshold and guidance noise levels for foraging marbled murrelets. The guideline of 150 dB single strike SEL is now also recognized by USFWS as EQ, wherein it is assumed that energy from pile strikes below this SEL does not accumulate to cause injury. USFWS also recognizes a behavioral threshold of 150 $dB_{RMS}$, in addition to a non-injurious auditory threshold of 183 dB SEL (i.e., temporary threshold shift in hearing due to temporary loss of cochlear hair cells), an injurious auditory threshold of 202 dB SEL (i.e., permanent threshold shift in hearing due to permanent loss of cochlear hair cells), and a non-auditory injury (i.e. barotrauma) threshold of 208 db SEL. Whether or not *take* actually occurs at these levels is dependent on numerous factors as is mentioned above.

NMFS is currently developing comprehensive guidance on sound levels likely to cause injury and behavioral disturbance in the context of the ESA and Marine Mammal Protection Act (MMPA). Until formal guidance is available, NMFS uses conservative thresholds of received SPLs from broadband sounds that may cause injury or behavioral disturbance to marine mammals (<http://www.nwr.noaa.gov/Marine-Mammals/MM-sound-thrshld.cfm>). These thresholds are summarized below.

Currently the injury threshold for impulse noises (such as impact pile driving) is identified as 180 $dB_{RMS}$ for whales and 190 $dB_{RMS}$ for pinnipeds. The underwater disturbance threshold for whales and pinnipeds is 160 $dB_{RMS}$ for impulse noises and 120 $dB_{RMS}$ for non-impulse, continuous noises (i.e., vibratory pile driving). NMFS has also defined in-air thresholds for disturbance for hauled-out pinnipeds. The thresholds are 90 $dB_{RMS}$ (unweighted) for harbor seals and 100 $dB_{RMS}$ (unweighted) re: 20 µPa for all other pinnipeds. The equations and procedures described in Section 7.1.4.2 can be used to determine the extent of project related noise above the airborne disturbance threshold for sea lions. The next section presents how to determine the extent of pile installation noise over the underwater disturbance and injury thresholds for marine mammals and other species. The following section is consistent with recent NOAA guidance (January 2012) that was developed to outline how to more accurately estimate sound propagation for pile driving sounds relevant to marine mammals. This guidance is available on the web at: <http://www.nwr.noaa.gov/Marine-Mammals/MM-sound-areas.cfm>.

### *7.2.4.5 Extent of Project-Related Noise and Effect Determinations*

The threshold levels established above can be used to define the zone of potential impact for salmon, bull trout, marine mammals, and diving marbled murrelets. For example, the zone of impact for injury to these species would occur in the area where project-related noise has not yet attenuated below the injury threshold level. The zone of impact for behavioral disturbance would be the area where project-related noise has not yet attenuated to the disturbance threshold. These distances can be calculated by using the Practical Spreading Loss model above, substituting the threshold level for the ambient level to determine the transmission loss.

The following example uses the Practical Spreading Loss model to illustrate the procedure for determining the distance to peak, RMS, and SEL(cum) thresholds for fish, diving marbled murrelets, whales, and Steller sea lion.

1. **Estimate the peak, RMS, and single strike SEL levels for the project.** If site specific data for the location, pile size, and pile type are available, use them as an estimate of the expected source levels of pile driving noise for the project. If not, for impact pile driving, use Table 7-9, Pile Diameter and Noise Levels (also available at <http://www.wsdot.wa.gov/Environment/Biology/BA/BAguidance.htm#Noise>) to estimate the source level in decibels for peak and RMS SPLs and single strike SEL for various pile diameters and types. To assure the values are agreed to by the Services, they should be presented at a pre-BA meeting.

    - ***Example** – An impact hammer will install four 36-inch piles. No site specific data on pile driving noise is available. From*

*Table 7-9, at 10 meters, peak noise levels are estimated at 214 dB, RMS levels at 201 dB, and an SEL (single strike) at 186 dB.*

2. **Estimate the number of strikes per summation period.** The summation period is the number of piles **struck** in a period of time (typically this is per day) until there is a rest period (usually a 12- to 18-hour period) where no strikes occur. The Pile Strike Summary Table at <http://www.wsdot.wa.gov/Environment/Biology/BA/BAguidance.htm#Noise> provides data from previous projects on the number of pile strikes per day with hammer type energy ratings. The data in the tables can be used to calculate the cumulative SEL (SELcum). A link to the CalTrans Pile Driving Compendium is also provided for comparison.

    - ***Example** –Using data from the Pile Strike Summary Table, it was determined the conditions at the project site are most similar to the Anacortes ferry terminal. Therefore, the project is estimated to strike the four piles 2,494 times per day (total time for all four) for 1 day.*

3. **Estimate noise reduction from a bubble curtain or other noise attenuation device.** As stated previously, the use of a noise attenuation device can reduce the noise levels at the source. However, because of the large variability in the effectiveness of bubble curtains, the expected level of attenuation from these or any other noise attenuation device should be discussed with the Services prior to submitting the BA in a pre-BA meeting.

    - ***Example** – A bubble curtain will be used during impact pile driving. Based on past experience with this design of bubble curtain, at this location, a 10 dB reduction in noise levels is expected at 10 meters from the source.*

4. **Determine if the fish being evaluated in the area affected by pile driving are ≥2 grams or <2 grams.** NMFS is working on tables that list the month fish in each listed ESU reach 2 grams. This table is incomplete at this time, but may be posted at a later date on our website. Use site-specific ESU information for the area where the project is located, if available. Note that separate ESA and EFH analyses may be required. All marine and estuarine areas have fish less than 2 grams present at all times. The USFWS considers bull trout to be less than 2 grams in Washington where local populations occur in core areas (not in FMO) from December 15 to September 30 with the exception of the Puyallup core area, where bull trout may be less than 2 grams in local population areas from November 15 to August 30.

5. **Use the Practical Spreading Loss model to determine the extent of the distances to the thresholds for injury and potential disturbance effects for fish and marbled murrelets.** In order to determine the effectiveness of a noise attenuation device, some **hydroacoustic** measurements will be made without the device operating; therefore, estimates with and without the estimated reduction in SPL and SEL from a noise attenuation device must be calculated.

   - ***Example – TL = 15Log($R_1$/$R_2$), or solved for $R_1$, $R_1$ = ($10^{(TL/15)}$)($R_2$).*** *$R_1$ is the distance where noise attenuates to threshold levels, $R_2$ is the range of the known noise level, and TL is the amount of spreading loss (estimated noise level – threshold level). (Note: Calculators for TL are available at <[http://www.wsdot.wa.gov/Environment/Biology/BA/BAguidance.htm#Noise](http://www.wsdot.wa.gov/Environment/Biology/BA/BAguidance.htm#Noise)>. See NMFS calculator and USFWS Marbled Murrelet SEL calculator.)*

   - **Peak**

     ***Estimated distance to the injury threshold for fish***

     $$10 * 10^{((214-206))/15)} = 34 \text{ meters}$$

     *(With noise attenuation)* $10 * 10^{((204-206))/15)} = 7$ *meters*

   - **RMS**

     ***Estimated distance for potential behavioral effects for fish and diving murrelets***

     $$10 * 10^{((201-150)/15)} = 25{,}119 \text{ meters}$$

     *(With noise attenuation)* $10 * 10^{((191-150)/15)} = 5{,}412$ *meters*

     ***Estimated distance for potential disturbance effects for marine mammals( for impulse sound)***

     $$10 * 10^{((201-160)/15)} = 5{,}412 \text{ meters}$$

     *(With noise attenuation)* $10 * 10^{((191-160)/15)} = 1{,}166$ *meters*

     ***Estimated distance for potential injury for cetaceans***

     $$10 * 10^{((201-180)/15)} = 251 \text{ meters}$$

     *(With noise attenuation)* $10 * 10^{((191-180)/15)} = 54$ *meters*

     ***Estimated distance for potential injury for Steller sea lions (pinnipeds)***

     $$10 * 10^{((201-190)/15)} = 54 \text{ meters}$$

*(With noise attenuation)* $10 * 10^{((191-190)/15)} = 12$ *meters*

- **SEL(cum) (for fish). Determine if you have "stationary" fish or "mobile" fish.** Unless you are in a project location where you know listed fish will be moving through the injury and behavioral threshold areas, use the calculation for stationary fish. If you have "moving" fish and the Services agree, then use the NMFS calculator for moving fish. This calculator is only available from NMFS.

*SEL (cum) = SEL(single strike at ~ 10 meters) + 10 Log * (# strikes)*

$$186 + 10\text{Log}(2{,}494) = 220 \text{ dB}$$

*(With noise attenuation)* $176 * 10\text{Log}(2{,}494) = 210$ *dB*

It is important to note that NMFS assumes that single strike SELs below 150 dB do not accumulate to cause injury. This concept, effective quiet (EQ), is built into its calculator for assessing pile driving injury to fish from noise. So if the distances calculated to the cumulative SEL thresholds described above (183 $dB_{SEL}$ and 187 $dB_{SEL}$) are greater than the distance calculated to effective quiet, the calculator will default to the effective quiet distance when defining the area of injury.

***Estimated distance to injury threshold for fish ≥2 grams***

$$10 * 10^{(220-187)/15)} = 1{,}577 \text{ meters}$$

*(With noise attenuation)* $10 * 10^{((210-187))/15)} = 340$ *meters*

***Estimated distance to injury threshold for fish <2 grams***

$$10 * 10^{((220-183)/15)} = 2{,}929 \text{ meters}$$

*(With noise attenuation)* $10 * 10^{((210-183))/15)} = 631$ *meters*

***Estimated distance to effective quiet –*** *To calculate the distance to effective quiet, the same Practical Spreading Loss equation is used, but rather than using the cumulative SEL value (220 dB) minus the threshold SEL (187 or 183 dB)/15 as the exponent, use the estimated SEL for the pile driving noise (186 dB) minus Effective Quiet (150 dB)/15 as the exponent. The correct equation is provided below for this example:*

$$10 * 10^{((186-150)/15)} = 2{,}512 \text{ meters}$$

The distance calculated to the 187 db cumulative SEL threshold calculated above is less than EQ, so the 1,577 meter distance is used to define the extent of injury for fish >2 grams. However, the distance calculated to the 183 db cumulative SEL threshold calculated above, exceeds the distance calculated to effective quiet, the so the biologist should default to the effective quiet distance (2, 512 meters) when defining the area of injury for fish <2 grams.

- **SEL(cum) (for diving marbled murrelets).** Remember there are three different injury thresholds to evaluate for marbled murrelets now: one for temporary hearing impacts (non-injurious auditory), one for permanent hearing impacts (injurious auditory), and one for non-auditory injury (i.e. barotrauma). The USFWS calculator can be used to determine the distances to these thresholds.

  *SEL (cum) = SEL(single strike at ~ 10 meters) + 10 Log * (# strikes)*

  $$186 + 10Log(2{,}494) = 220 \text{ dB}$$

  *(With noise attenuation)* $176 * 10Log(2{,}494) = 210 \text{ dB}$

It is important to note that USFWS assumes that single strike SELs below 150 dB do not accumulate to cause injury. This concept, effective quiet (EQ), is built into its calculator for assessing pile driving injury to fish and diving marbled murrelets from noise. So if the distances calculated to the cumulative SEL thresholds described above are greater than the distance calculated to effective quiet, the calculator will default to the effective quiet distance when defining the area of injury.

***Estimated distance to non-injurious auditory threshold (183 dB SEL)***

$$10 * 10^{((220-183)/15)} = 2{,}929 \text{ meters}$$

*(With noise attenuation)* $10 * 10^{((210-183))/15)} = 631$ *meters*

***Estimated distance to injurious auditory threshold (202 dB SEL)***

$$10 * 10^{((220-202)/15)} = 158 \text{ meters}$$

*(With noise attenuation)* $10 * 10^{((210-202))/15)} = 34$ *meters*

***Estimated distance to non-auditory injury threshold (208 dB SEL)***

$$10 * 10^{((220-208)/15)} = 63 \text{ meters}$$

*(With noise attenuation)* $10 * 10^{((210-208))/15)} = 14$ *meters*

***Estimated distance to effective quiet –*** *To calculate the distance to effective quiet, the same Practical Spreading Loss equation is used, but rather than using the cumulative SEL value (220 dB) minus the threshold SEL /15 as the exponent, use the estimated SEL for the pile driving noise (186 dB) minus Effective Quiet (150dB)/15 as the exponent. The correct equation is provided below for this example:*

$$10 * 10^{((186-150)/15)} = 2,512 \text{ meters}$$

- The distance calculated to the 183 db cumulative SEL threshold calculated above, exceeds the distance calculated to effective quiet, the so the biologist should default to the effective quiet distance (2, 512 meters) when defining the area of non-injurious auditory effects.

- *Therefore, according to the Practical Spreading Loss model, in open water with no noise attenuation, impact pile driving noise would be expected to attenuate to the injury threshold for fish at 34 meters for peak levels, 1,577 meters for SEL(cum) levels for fish ≥2 grams, and 2,512 meters for fish <2 grams. For this project with 2,494 pile strikes, the most conservative metric to estimate the distance to the injury threshold for fish would be the SEL(cum).*

- *The distance to the injury threshold for cetaceans and Steller sea lions is estimated to extend 251 meters and 54 meters, respectively, in open water without the noise attenuation.*

- *For marbled murrelets, the distance to the non-injurious auditory threshold would be 2,512 meters, 158 meters for the auditory injury threshold, and 63 meters for potential non-auditory injury (i.e. barotraumas).*

- *In open water with no noise attenuation, pile driving noise would be expected to attenuate to the behavior threshold for fish and marbled murrelets at 25.1 kilometers.*

- *In open water with no noise attenuation, pile driving noise would be expected to attenuate to the disturbance threshold for marine mammals at 5.4 kilometers.*

- *These distances would be worst case and would only be expected to occur when the noise attenuation device was not in operation. Therefore, also include in the BA the expected distances to the thresholds with the expected reduction from the noise attenuation device.*

- ***Map the extent of the distance to each threshold.*** *As stated in the previous example, noise pressure travels in a linear direction (concentrically) away from the source; when the noise intersects a landmass, it is assumed that it does not travel through the land mass or reflect off of the land mass. Therefore, the project* *biologist should determine where the thresholds extend based on land masses.*

6. **Estimate the area being affected.** For the area within a mapped circular threshold, the area is calculated simply as $\pi R^2$. For irregular shaped areas, Geographic Information System tools can be used.

7. **If possible, estimate how many individuals are being affected.** If fish distribution, murrelet foraging, or marine mammal distribution data are available, use it to estimate the number of individuals in the affected area.

As mentioned above, the disturbance threshold should be considered the “may affect” threshold. The project effect determination for fish, for example, is not automatically a “not likely to adversely affect” merely because the noise level is above the disturbance threshold but below the injury threshold. Other project conditions, such as timing, duration, or life history information may also be necessary to ensure the effects from noise are insignificant or discountable. Likewise, behavioral disruption could also result in a likely to adversely affect situation if measures cannot be taken to minimize effects.

Even if a species is outside the zone of behavioral disruption (i.e., located below 150 dB RMS for salmonids and diving marbled murrelet, or below 160 dB RMS for marine mammals), a *no effect* determination may not be warranted. For a *no effect* determination, the species must be located in a zone where all underwater noise has attenuated to baseline levels.

It is important to realize when using the threshold levels identified above that the injury and disturbance thresholds are measured in three different metrics, $dB_{peak}$, dB $SEL_{(cum)}$, and $dB_{RMS}$. When using the models, it is crucial to compare like values to ensure accuracy. For example, a noise level measured in peak should not be used to determine the distance of the disturbance threshold, which is measured in RMS. Likewise, using an RMS noise level to identify the injury threshold (peak) will lead to incorrect results.

### *7.2.4.6 Anticipated Project Requirements*

The Services have completed recent consultations that have developed reasonable and prudent measures requiring underwater pile driving projects to mitigate for potential impacts. The bulleted statements below summarize what anticipated requirements may be for underwater pile driving projects:

- Vibratory hammers may be required where substrate conditions allow.

- Hydroacoustic monitoring will likely be required on any project with impact pile driving. A standard plan to conduct hydroacoustic monitoring is required for WSDOT projects. A template for the standard plan is available at <http://www.wsdot.wa.gov/Environment/Biology/BA/BAtemplates.htm>. The template should be filled in with project specific information and then included in the BA as an appendix. Check the webpage above for the most current version of the template.

- Visual marine mammal monitoring will likely be required for listed species that may be potentially present. For listed marine mammal species, such as the southern resident killer whale, humpback whale, or Steller sea lion, shut-down of impact or vibratory pile driving must occur for the area within the behavioral threshold, unless incidental take has been granted through both an ESA Section 7 consultation and an MMPA authorization. Shut-down of pile driving will always be required if any marine mammal (listed or not listed) approaches the injury zone.

- Visual marbled murrelet monitoring will likely be required if a project occurs where marbled murrelets may be potentially present. Shut-down of impact pile driving must occur for the area within the behavioral threshold, unless incidental take has been granted through both an ESA Section 7 consultation. Shut-down of pile driving will always be required if any marbled murrelet approaches the injury zone.

- If the use of a bubble curtain or other attenuation method is not proposed, the Services may require the use of an attenuation method if SPLs or cumulative SELs exceed the threshold limits for a certain amount of time. For example, pile driving without a bubble curtain may be allowed only if constant monitoring indicates the cumulative SEL levels do not exceed either the 183 dB or 187 dB cumulative SEL thresholds and peak levels never exceed 206 dB. If the cumulative SEL levels exceed either 183 dB or 187 dB, OR peak values exceed the 206 dB threshold, a bubble curtain will likely be required. However, these conditions are site and project specific.

- The design of any bubble curtain to be used will need to be reviewed in advance by the Services.

A monitoring reports should be submitted to the Services after pile driving is completed. Required report details are determined during consultation or outlined in the standard templates available at <http://www.wsdot.wa.gov/Environment/Biology/BA/BAtemplates.htm>.