APPENDIX I

Noise and Vibration Background Data

NOISE BACKGROUND

Characteristics of Sound

Sound is a pressure wave transmitted through the air. When an object vibrates, it radiates part of its energy as acoustical pressure in the form of a sound wave. Sound can be described in terms of amplitude (loudness), frequency (pitch), or duration (time). The standard unit of measurement of the loudness of sound is the decibel (dB). The human hearing system is not equally sensitive to sound at all frequencies. Sound waves below 16 Hz are not heard at all and are "felt" more as a vibration. Similarly, while people with extremely sensitive hearing can hear sounds as high as 20,000 Hz, most people cannot hear above 15,000 Hz. In all cases, hearing acuity falls off rapidly above about 10,000 Hz and below about 200 Hz. Since the human ear is not equally sensitive to sound at all frequencies, a special frequency-dependent rating scale is usually used to relate noise to human sensitivity. The A-weighted decibel scale (dBA) performs this compensation by discriminating against frequencies in a manner approximating the sensitivity of the human ear.

Because of the physical characteristics of noise transmission and noise perception, the relative loudness of sound does not closely match the actual amounts of sound energy. Table 1, Change in Sound Pressure Level, dB, presents the subjective effect of changes in sound pressure levels. Typical human hearing can detect changes of approximately 3 dBA or greater under normal conditions. Changes of 1 to 3 dBA are detectable under quiet, controlled conditions and changes of less than 1 dBA are usually indiscernible. A change of 5 dBA or greater is typically noticeable to most people in an exterior environment and a change of 10 dBA is perceived as a doubling (or halving) of the noise.

Table 1Change in Sound Pressure Level, dB				
Change in Apparent Loudness				
\pm 3 dB	Threshold of human perceptibility			
\pm 5 dB	Clearly noticeable change in noise level			
\pm 10 dB	Half or twice as loud			
\pm 20 dB	Much quieter or louder			
Source: Bies and Hansen	2003.			

Point and Line Sources

Noise may be generated from a point source, such as a piece of construction equipment, or from a line source, such as a road containing moving vehicles. Because noise spreads in an ever-widening pattern, the given amount of noise striking an object, such as an eardrum, is reduced with distance from the source. This is known as "spreading loss." The typical spreading loss for point source noise is 6 dBA per doubling of the distance from the noise source.

A line source of noise, such as vehicles proceeding down a roadway, would also be reduced with distance, but the rate of reduction is affected by of both distance and the type of terrain over which the

noise passes. Hard sites, such as developed areas with paving, reduce noise at a rate of 3 dBA per doubling of the distance while soft sites, such as undeveloped areas, open space and vegetated areas reduce noise at a rate of 4.5 dBA per doubling of the distance. These represent the extremes and most areas would actually contain a combination of hard and soft elements with the noise reduction placed somewhere in between these two factors. Unfortunately the only way to actually determine the absolute amount of attenuation that an area provides is through field measurement under operating conditions with subsequent noise level measurements conducted at varying distances from a constant noise source.

Objects that block the line of sight attenuate the noise source if the receptor is located within the "shadow" of the blockage (such as behind a sound wall). If a receptor is located behind the wall, but has a view of the source, the wall would do little to reduce the noise. Additionally, a receptor located on the same side of the wall as the noise source may experience an increase in the perceived noise level, as the wall would reflect noise back to the receptor compounding the noise.

Noise Metrics

Several rating scales (or noise "metrics") exist to analyze adverse effects of noise, including trafficgenerated noise, on a community. These scales include the equivalent noise level (L_{eq}), the community noise equivalent level (CNEL) and the day/night noise level (L_{dn}). L_{eq} is a measurement of the sound energy level averaged over a specified time period.

The CNEL noise metric is based on 24 hours of measurement. CNEL differs from L_{eq} in that it applies a time-weighted factor designed to emphasize noise events that occur during the evening and nighttime hours (when quiet time and sleep disturbance is of particular concern). Noise occurring during the daytime period (7:00 AM to 7:00 PM) receives no penalty. Noise produced during the evening time period (7:00 to 10:00 PM) is penalized by 5 dB, while nighttime (10:00 PM to 7:00 AM) noise is penalized by 10 dB. The L_{dn} noise metric is similar to the CNEL metric except that the period from 7:00 to 10:00 PM receives no penalty. Both the CNEL and L_{dn} metrics yield approximately the same 24-hour value (within 1 dB) with the CNEL being the more restrictive (i.e., higher) of the two.

Psychological and Physiological Effects of Noise

Physical damage to human hearing begins at prolonged exposure to noise levels higher than 85 dBA. Exposure to high noise levels affects the entire system, with prolonged noise exposure in excess of 75 dBA increasing body tensions, thereby affecting blood pressure and functions of the heart and the nervous system. In comparison, extended periods of noise exposure above 90 dBA would result in permanent cell damage. When the noise level reaches 120 dBA, a tickling sensation occurs in the human ear even with short-term exposure. This level of noise is called the threshold of feeling. As the sound reaches 140 dBA, the tickling sensation is replaced by the feeling of pain in the ear. This is called the threshold of pain. A sound level of 160 to 165 dBA will result in dizziness or loss of equilibrium. A sound level of 190 dBA will rupture the eardrum and permanently damage the inner ear. Table 2 shows typical noise levels from various noise sources.

Table 2 Typical Noise Levels from Noise Sources						
Noise Level (dBA)	Common Indoor Activities					
110	Rock Band					
100						
90						
	Food Blender at 3 feet					
80	Garbage Disposal at 3 feet					
70	Vacuum Cleaner at 10 feet					
	Normal speech at 3 feet					
60						
	Large Business Office					
50	Dishwasher Next Room					
40	Theater, Large Conference Room (backgrour					
30	Library					
	Bedroom at Night, Concert Hall (backgroun					
20						
	Broadcast/Recording Studio					
10						
0	I owest Threshold of Human Hearing					
	Table 2 Dise Levels from N Noise Level (dBA) 110 100 90 80 80 70 60 50 40 30 20 10 10					

Vibration

Vibration is an oscillatory motion through a solid medium in which the motion's amplitude can be described in terms of displacement, velocity, or acceleration. Vibration is normally associated with activities such as railroads or vibration-intensive stationary sources, but can also be associated with construction equipment, such as jackhammers, pile drivers, and hydraulic hammers. Vibration displacement is the distance that a point on a surface moves away from its original static position. The instantaneous speed that a point on a surface moves is described as the velocity, and the rate of change of the speed is described as the acceleration. Each of these descriptors can be used to correlate vibration to human response, building damage, and acceptable equipment vibration levels. During the construction of a building, the operation of construction equipment could cause groundborne vibration. The three main wave types of concern in the propagation of groundborne vibrations are surface or Rayleigh waves, compression or P-waves, and shear or S-waves.

- Surface or Rayleigh waves travel along the ground surface. They carry most of their energy along an expanding cylindrical wave front, similar to the ripples produced by throwing a rock into a lake. The particle motion is more or less perpendicular to the direction of propagation (known as retrograde elliptical).
- Compression or P-waves are body waves that carry their energy along an expanding

spherical wave front. The particle motion in these waves is longitudinal, in a push-pull motion. P-waves are analogous to airborne sound waves.

 Shear or S-waves are also body waves, carrying their energy along an expanding spherical wave front. Unlike P-waves, however, the particle motion is transverse, or perpendicular to the direction of propagation.

The peak particle velocity (PPV) or the root mean square (RMS) velocity is usually used to describe vibration amplitudes. PPV is defined as the maximum instantaneous peak of the vibration signal and RMS is defined as the square root of the average of the squared amplitude of the signal. PPV is more appropriate for evaluating potential building damage, whereas RMS is typically more suitable for evaluating human response.

The units for PPV and RMS velocity are normally inches per second (in/sec). Often, vibration is presented and discussed in dB units to compress the range of numbers required to describe the vibration. All PPV and RMS velocity are in in/sec and all vibration levels in this study are in dB relative to 1 micro-inch per second (abbreviated as VdB). The threshold of perception is approximately 65 VdB. Typically groundborne vibration generated by manmade activities attenuates rapidly with distance from the source of the vibration. Manmade vibration problems are usually confined to short distances (500 feet or less) from the source.

Construction generally includes a wide range of activities that can generate groundborne vibration. In general, demolition of structures generates the highest vibrations. Vibratory compactors or rollers, pile drivers, and pavement breakers can generate perceptible amounts of vibration at distances within 200 feet of the vibration sources. Heavy trucks can also generate groundborne vibrations that vary, depending on vehicle type, weight, and pavement conditions. Potholes, pavement joints, discontinuities, differential settlement of pavement, etc., all increase the vibration levels from vehicles passing over a road surface. Construction vibration is normally of greater concern than vibration of normal traffic on streets and freeways with smooth pavement conditions. Trains generate substantial quantities of vibration due to their engines, steel wheels, and heavy loads.

Sensitive Receptors

Certain land uses are particularly sensitive to noise and vibration. Noise- and vibration-sensitive uses include land uses where quiet environments are necessary for enjoyment and public health and safety. Residences, schools, guest lodging, libraries, religious institutions, hospitals, nursing homes, and passive recreation areas are generally more sensitive to noise than commercial and industrial land use.

NOISE REGULATORY ENVIRONMENT

To limit exposure of people to intrusive and physically and/or psychologically damaging noise levels, the federal government, the State of California, some county governments, and most municipalities in the state have established standards and ordinances to control noise.

Noise

The United States Environmental Protection Agency (USEPA) has developed general guidelines for recommended maximum noise levels to protect public health and welfare and the hearing of workers exposed to occupational noise.

Vibration

The Federal Transit Administration (FTA) provides criteria for acceptable levels of groundborne vibration for various types of land uses that are sensitive to vibration. These criteria can be separated into annoyance effects and architectural damage effects due to vibration.

Vibration Annoyance

Table 3, *Groundborne Vibration Criteria – Human Annoyance*, shows the FTA and Caltrans vibration criteria to evaluate vibration-related annoyance due to resonances of the structural components of a building. These criteria are based on the work of many researchers that suggested that humans are sensitive to vibration velocities in the range of 8 to 80 Hz.

Table 3 Groundborne Vibration Criteria – Human Annoyance							
Land Use Category	Vibration Velocity Level (VdB) ¹	Description					
Workshop	90	Distinctly felt vibration. Appropriate to workshops and non-sensitive areas					
Office	84	Felt vibration. Appropriate to offices and non-sensitive areas.					
Residential – Daytime	78	Barely felt vibration. Adequate for computer equipment.					
Residential – Nighttime	75	Vibration not felt, but groundborne noise may be audible inside quiet rooms.					
Source: FTA 2006 and Caltrans	2004.						

¹ As measured in 1/3-octave bands of frequency over the frequency ranges of 8 to 80 Hz.

Vibration-Related Architectural Damage

Structures amplify groundborne vibration and wood-frame buildings, such as typical residential structures, are more affected by ground vibration than heavier buildings. The level at which groundborne vibration is strong enough to cause architectural damage has not been determined conclusively. The most conservative estimates are reflected in the FTA standards, shown in Table 4.

Table 4Groundborne Vibration Impact Criteria – Architectural Damage					
Building Category	PPV (in/sec)				
I. Reinforced concrete, steel, or timber (no plaster)	0.5				
II. Engineered concrete and masonry (no plaster)	0.3				
III. Nonengineered timber and masonry buildings	0.2				
IV. Buildings extremely susceptible to vibration damage	0.12				
Source: FTA 2006					

State

Multiple-family housing in the State of California is subject to the environmental noise limits set forth in the 2007 California Building Code (Chapter 12, Appendix Section 1207.11.2). The maximum interior noise level at any habitable room due to exterior noise is 45 dBA L_{dn} or, equivalently, 45 dBA CNEL

Noise Compatibility

Cities and counties in California are preempted by federal law from controlling noise generated from most mobile sources, including noise generated by vehicles and trucks on the roadway, trains on the railroad, and airplanes. Table 5 shows a land use compatibility chart for community noise adopted by the State of California as part of the General Plan Guidelines.¹ This table provides urban planners with a tool to gauge the compatibility of new land uses relative to existing and future noise levels.

¹ California Office of Noise Control, *Guidelines for the Preparation and Content of Noise Elements of the General Plan,* February 1976. Included in the State of California General Plan Guidelines.

Land Use Compatibility for Co	ommunn	y N	oise	Expo				
Land Lloop		UNEL (dBA)						00
			<u></u>	3	00	70	75	00
Residential-Low Density								
Single Family, Duplex, Mobile Homes								
		1111			3			
Residential- Multiple Family								
		1111			3			
Transient Lodging, Motels, Hotels								
						(/////		
		1111	11111	11111				
Schools, Libraries, Churches, Hospitals, Nursing Homes								
						(/////		
				1				
Auditoriums, Concert Halls, Amphitheatres		<u> </u>					/////	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
					//////			
]		
Sports Arena, Outdoor Spectator Sports								//////
						,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,		
		IIII		IIIII	<u>inni</u>	¥	-	
Playgrounds, Neighborhood Parks								//////
				İ				
					liilii	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,		
Golf Courses, Riding Stables, Water Recreation, Cemeteries								
				(11111				
Office Buildings, Businesses, Commercial and Professional						1	/////	//////
					,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,			
Industrial, Manufacturing, Utilities, Agricultural								//////
Explanatory	Notes							
Normally Acceptable:		Nor	mally U	naccep	table:	ont ob	Id aana	lluba
specified faild use is satisfactory based upon the assumption that any buildings involved are of normal		disco	construe	lf new c	uevelopm constructi	on does	iu yenera proceed	ny be a
conventional construction, without any special noise		detai	iled analy	/sis of th	ne noise r	eduction	requirem	ents
insulation requirements.		mus	t be mad	e and ne	eded noi	se insula [.]	tion featu	res
	///////////////////////////////////////	inciu	iaea in th	ie aesigr	1.			

Table 5

Clearly Unacceptable: **Conditionally Acceptable:** New construction or development should generally not New construction or development should be undertaken be undertaken. only after a detailed analysis of the noise reduction requirements is made and the needed noise insulation features included in the design. Conventional construction, but with closed windows and fresh air supply systems or air conditioning will normally suffice. Source: Office of Noise Control, Guidelines for the Preparation and Content of Noise Elements of the General Plan, February 1976. Included in the Governor's Office of Planning and Research, California, *General Plan Guidelines*, Appendix C, October 2003.

LOCAL - City of Sausalito

a. Sausalito General Plan

The Health and Safety Element of General Plan sets forth the policies to assess and control environmental noise.

The City's Health and Safety Element includes a noise and land use compatibility table to identify appropriate land uses at various levels of noise exposure. Residential land uses are considered normally acceptable for ambient noise levels of up to 60 dBA CNEL. For ambient noise levels between 60 and 75 dBA CNEL, the development of residential uses are considered conditionally acceptable. This is described further in response a) below.

In addition, the City has established interior noise guidelines for various land uses. For residential uses the maximum interior noise level is 45 dBA L_{dn} or CNEL. New development is required to incorporate design elements and sound insulation features to meet acceptable interior noise levels.

b. City of Sausalito Municipal Code

Walnut Creek regulates noise in Chapter 12.16 (Noise Control) of the Municipal Code. The Municipal Code does not establish quantitative noise limits. The standards which shall be considered in determining whether a violation of the Noise Control regulations in the Municipal Code include, but are not be limited to, the following:

- The level of the noise;
- The intensity of the noise;
- Whether the nature of the noise is usual or unusual;
- Whether the origin of the noise is natural or unnatural;
- The level and intensity of the background noise if any;
- The proximity of the noise to residential sleeping facilities;
- The nature and zoning of the area within which the noise emanates;
- The density of the inhabitation of the area within which the noise emanates;
- The time of the day or night the noise occurs;
- The duration of the noise;
- Whether the noise is recurrent, intermittent, or constant; and
- Whether the noise is produced by a commercial or noncommercial activity.

Subsection 12.16.140 addresses construction, including demolition, excavation, alteration and repair of buildings and limits these activities between the hours of 8:00 a.m. and 6:00 p.m. on weekdays, which are not holidays, between 9:00 a.m. and 5:00 p.m. on Saturdays, and between 9:00 a.m. and 7:00 p.m. on holidays officially recognized by the City of Sausalito."

REFERENCES

California Department of Transportation (Caltrans). 2004, June. Transportation- and Construction-Induced Vibration Guidance Manual. Prepared by ICF International.

——. 2009. Technical Noise Supplement.

Bies, David A. and Colin H. Hansen. 2003. *Engineering Noise Control: Theory and Practice*. 3rd ed. New York: Spoon Press.

Federal Transit Administration (FTA). 2006, May. *Transit Noise and Vibration Impact Assessment*. United States Department of Transportation. FTA-VA-90-1003-06.

Governor's Office of Planning and Research. 2003, October. State of California General Plan Guidelines.

United States Environmental Protection Agency (USEPA). 1974, March. Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety. Office of Noise Abatement and Control.