SR-240, YAKIMA RIVER BRIDGE AT RICHLAND

UNDERWATER SOUND LEVELS ASSOCIATED WITH CONSTRUCTION OF THE SR 240 BRIDGE ON THE YAKIMA RIVER AT RICHLAND (DRAFT)

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EXECUTIVE SUMMARY

This technical report describes the underwater sound levels associated with the pile driving activities for the construction of the eastbound lanes of the SR 240 Bridge over the Yakima River (MP 36.25 to MP 36.84). Analysis of sound level impacts in the project area is based on the criteria set by the National Oceanic and Atmospheric Administration (NOAA) and existing knowledge available from the literature. Mitigation measures that may be taken to avoid or reduce potential noise impacts are discussed where appropriate.

Several descriptors are used to describe underwater noise impacts. Two common descriptors are the instantaneous peak sound pressure level (SPL) and the Root Mean Square (RMS) pressure level during the impulse, which is sometimes referred to as the SPL or RMS level. The peak pressure is the instantaneous maximum or minimum pressure observed during each pulse and can be presented as a pressure (e.g., μPa) or decibel (dB) referenced (re:) to some standard pressure like 1 μPa. The SPL or RMS level is the square root of the energy divided by the duration. This level, presented in dB re: 1 μPa, is equivalent to the mean square pressure level of the pulse. It has been used by NOAA Fisheries as criteria for judging impacts to marine mammals from underwater impulse-type sounds. The majority of literature uses peak sound pressure levels to evaluate injuries to fish. Except where otherwise noted, sound levels reported in this discussion are peak sound pressure levels expressed in kPa and also converted to dB re: 1 μPa.

Underwater sound levels were several orders of magnitude lower than the limits of 75 kPa required by NOAA for this project (Table 1).

Table 1: Summary of Underwater Sound Level Impacts and Mitigation

		Sound Levels @ 30 ft. (kPa/dB)	**Sound Levels @ 90 ft. (kPa/dB)**		
Pile	**Water Depth (ft.)**	**Mid Depth[1]**	**Bottom Depth[2]**	**NOAA Limit (kPa/dB)**	**Mitigation Measures**
1	5.3	0.001/120	0.003/130	75/218	None
2	2.7	0.002/126	0.009/139	75/218	None
3	2.5	0.432/173	0.111/161	75/218	None
4	2.5	0.288/169	0.075/158	75/218	None
5	2.5	0.322/170	0.391/172	75/218	None

1 – For pile #1 = 2.6 ft., for pile #2 = 1.4 ft., for piles #3, #4 & #5 = 1.2 ft.
2 – For pile #1 = 4.2 ft., for pile #2 = 1.8 ft., for piles #3, #4 & #5 = 1.4 ft.

INTRODUCTION

This technical report presents results of underwater sound levels measured during the driving of the first five piles in the Yakima River during July 2003 (Contract number: C6522 in South Central Region). The driving of 16-inch diameter piles was conducted as par of the design for the replacement of the SR 240 Bridge on the south side of SR 240. Figure 1 is a vicinity map showing the general location of the pile driving activity.

PROJECT DESCRIPTION

This contract provides for the improvements of .59 miles of SR 240 in Benton County, with the replacement of the existing bridge with two new bridges and with the work necessary to tie the new bridges into the alignments east and west on the river crossing. This work consists of bridge demolition, construction of concrete pre-stressed girder bridges with approach slabs (including pile driving), earthwork, clearing and grubbing, removing asphalt concrete pavement, grading, surfacing, paving with asphalt concrete pavement, construction of temporary and permanent erosion control, concrete barrier placement, bicycle / pedestrian pathway construction, channelization, pavement markings, illumination, permanent signing, planting, construction of environmental mitigation areas and other work.

The first phase of work on this project described in this report is the construction of the eastbound bridge on the south side of SR 240.

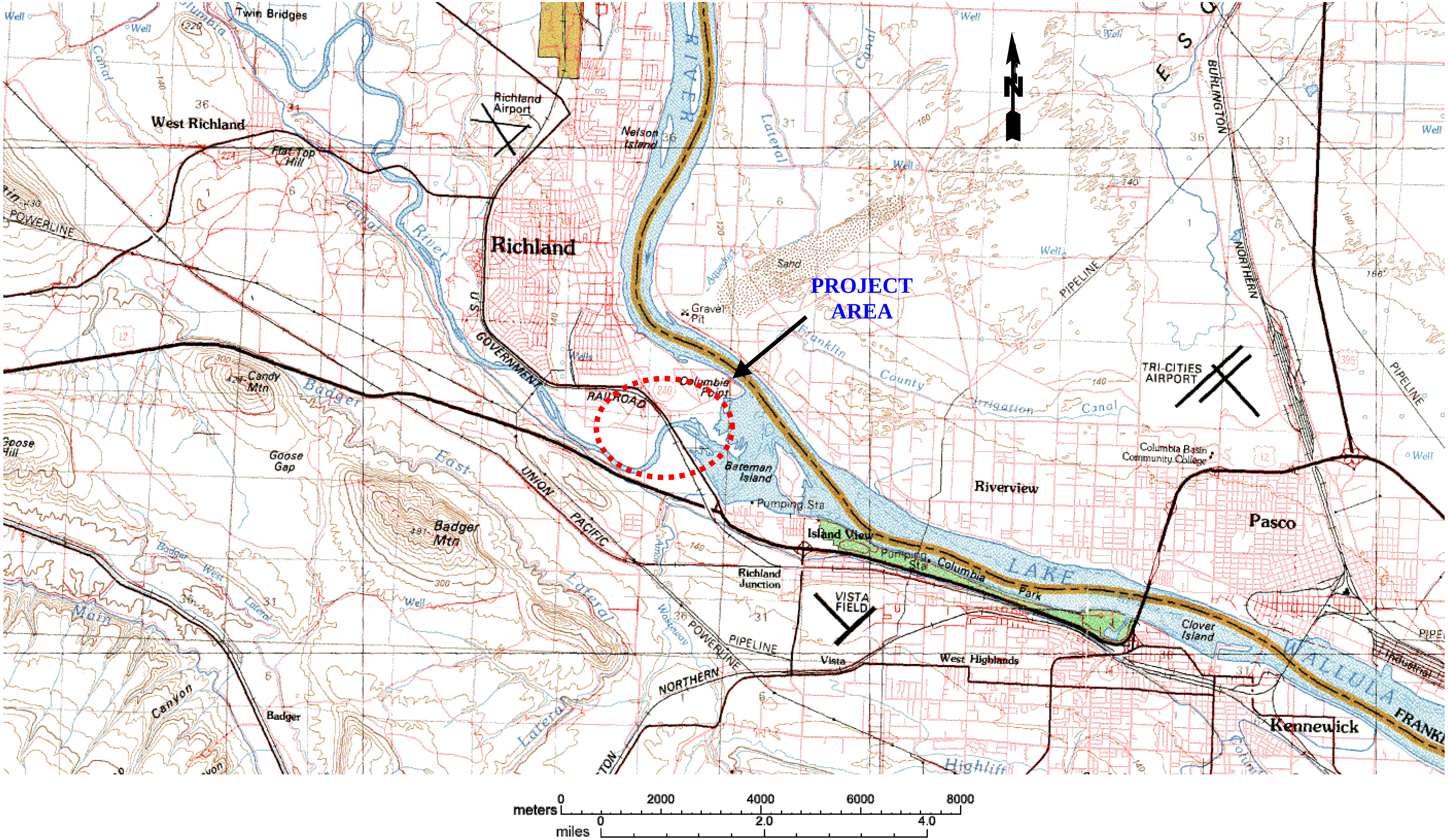


Figure 1: Vicinity Map

UNDERWATER SOUND LEVELS

CHARACTERISTICS OF UNDERWATER SOUND

Several descriptors are used to describe underwater noise impacts. Two common descriptors are the instantaneous peak sound pressure level (SPL) and the Root Mean Square (RMS) pressure level during the impulse, which is sometimes referred to as the SPL or RMS level respectively. The peak pressure is the instantaneous maximum or minimum pressure observed during each pulse and can be presented as a pressure such as Kilopascals (kPa) or decibel (dB) referenced to some standard pressure like 1 micropascal (μPa). The SPL or RMS level is the square root of the energy divided by the duration. This level, presented in dB re: 1 μPa, is equivalent to the mean square pressure level of the pulse. It has been used by NOAA Fisheries in criteria for judging impacts to marine mammals from underwater impulse-type sounds. The majority of literature uses peak sound pressures to evaluate injuries to fish. Except where otherwise noted, sound levels reported in this report are peak sound pressure levels expressed in kPa and also converted to dB re: 1 μPa.

Rise time is another descriptor used in wave form analysis to quantify the energy being generated. Rise time is the time in microseconds (ms) it takes the wave form to go from background levels to peak level.

Since water and air are two distinctly different media, a different sound pressure level reference pressure is used for each. In water, the reference pressure for water is 1 μPa whereas the reference pressure for air is 20 μPa. The equation to calculate the sound pressure level is:

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

For comparison, an underwater sound level of equal perceived loudness would be 62 dB higher to a comparable sound level in air.

METHODOLOGY

Underwater sound level measurements were made by WSDOT for the first five piles driven in water on two separate days. On the first day measurements were made from a 12-foot aluminum boat anchored at distances of 30 feet and 90 feet from the pile being driven.

Underwater sound levels were measured using two Reson TC 4013 hydrophones at bottom (approximately 1 foot above bottom to avoid transmission of sound from the bottom) and mid-water level. The measurement system includes a Brüel and Kjær Nexus type 2692 4-channel signal conditioner, which kept the high underwater sound levels from overloading the signal analyzer (Figure 2). The output of the Nexus signal conditioner was received by a Dactron Photon 4-channel signal spectrum analyzer which was attached to an Itronix GoBook II laptop computer. The waveform of the pile strikes along with the minimum, maximum, peak and RMS peak sound levels were captured and stored on the laptop hard drive for subsequent signal analysis. The system was calibrated in the field using a GRAS type 42AC high level pistonphone hydrophone calibrator with a hydrophone adaptor. The calibration signal was 141 dB re: 1 μPa. The noise levels produced by the calibrator and measured by the measurement system were within 2-3 dB and considered acceptable. A photograph of the system and its components are shown in Figure 2.

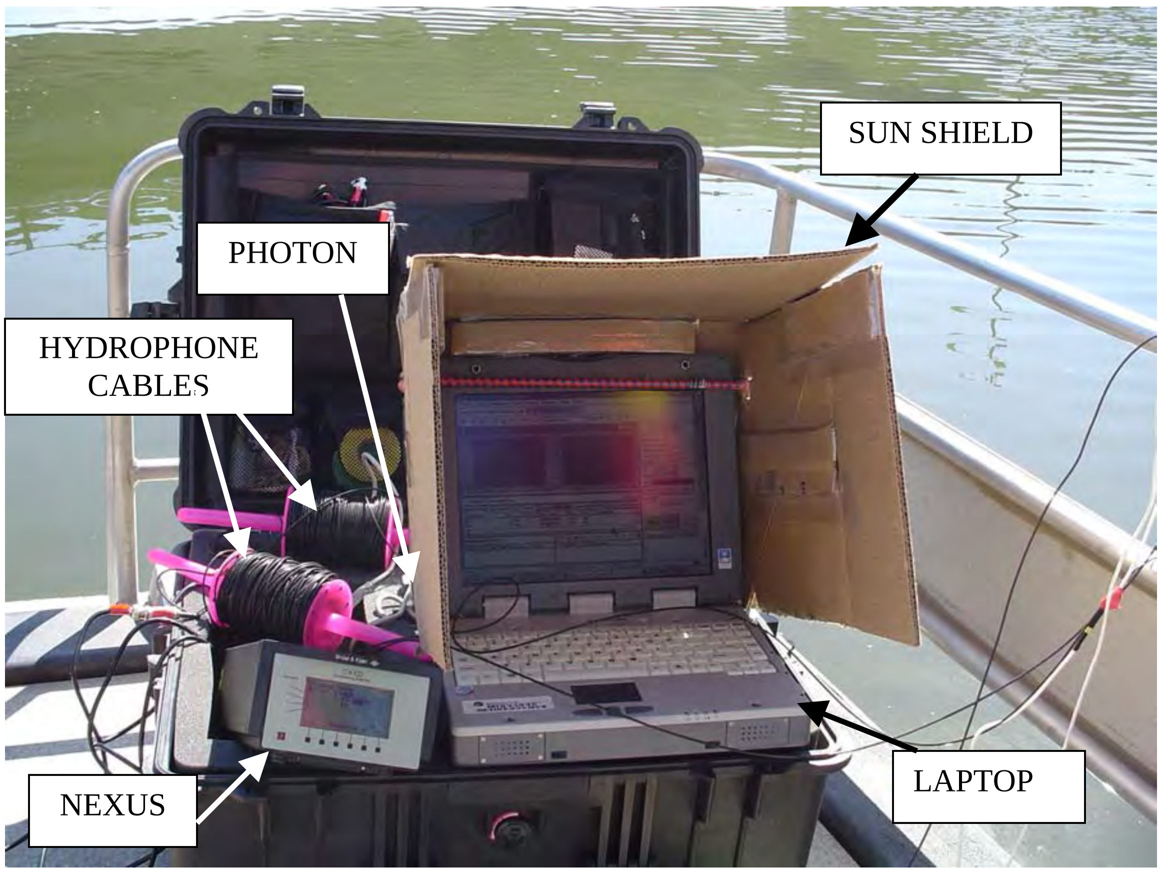


Figure 2: Underwater Sound Level Measurement Equipment

On day 1, (July 3, 2003) underwater sound level measurements were made for the first two piles driven in water from a 12-foot aluminum boat. The boat was anchored and the hydrophones were attached to a weighted nylon cord to so that the weight did not touch bottom. The boat was repositioned and anchored during pile driving to measure underwater sound levels at both 30-foot and 90-foot distances from the pile. Unfortunately, the waveform data recorded for the first two piles were lost when transferred to a CD. As a backup the peak levels at mid-water depth were recorded using a hydrophone attached to a hand held sound level meter and reported here. The underwater sound levels were measured in dB and we converted to kPa.

On day 2, (July 7, 2003) underwater sound level measurements were made from shore because the boat required repairs. The river water level was also approximately 2 feet lower than four days before. A wooden boom was constructed on site using two by four lumber and plastic floats. The hydrophones were hung off the far end of the boom at 30 and 90-foot distances from the pile being driven. Due to the difficulty and time it would take to reposition the boom to a second distance from the same pile the boom was left in place (either 30 or 90 feet from each pile) during the entire pile drive. Maximum water depth was 5.5 feet and minimum depth was 2.5 feet where measurements were made. Figure 3 shows the measurement locations.

Signal analysis software provided with the Photon was set at a sampling rates of one sample every 20.8 μs or 10.4 μs (48,000 or 96,000 bytes per second). It was determined that the 20.8 μs sampling rate gave enough resolution at the lowest possible sampling rate.

Water quality measurements were made prior to start of pile driving activities and during pile driving activities at a specified location down stream from the pile driving site to determine if there were any water quality impacts. Water quality parameters measured were water temperature, pH and turbidity.

The pile driver was an ICE Model 605 single-acting diesel pile hammer. It has a rated continuous energy of 81 kjoules with a maximum energy of 99 kjoules. Hammer weight is 13,900 lbs.

The substrate consisted of medium to very dense well to poorly graded gravel with sand, cobbles and boulders. The cobbles and boulders are nested in some areas. The soil is highly permeable and is generally found above elevation 310 to 320 feet. Below elevation 310 to 320 feet, dense to very dense non-plastic/low plasticity silt, sandy silt, and silty sand or poorly graded sand is present. Groundwater throughout the site is near the river level and follows the river level fluctuation.

Piles driven were open ended hollow steel piles, 16 inches in diameter with a ½ inch wall thickness. Piles were driven to refusal in all cases.

Each measured pile site is described below:

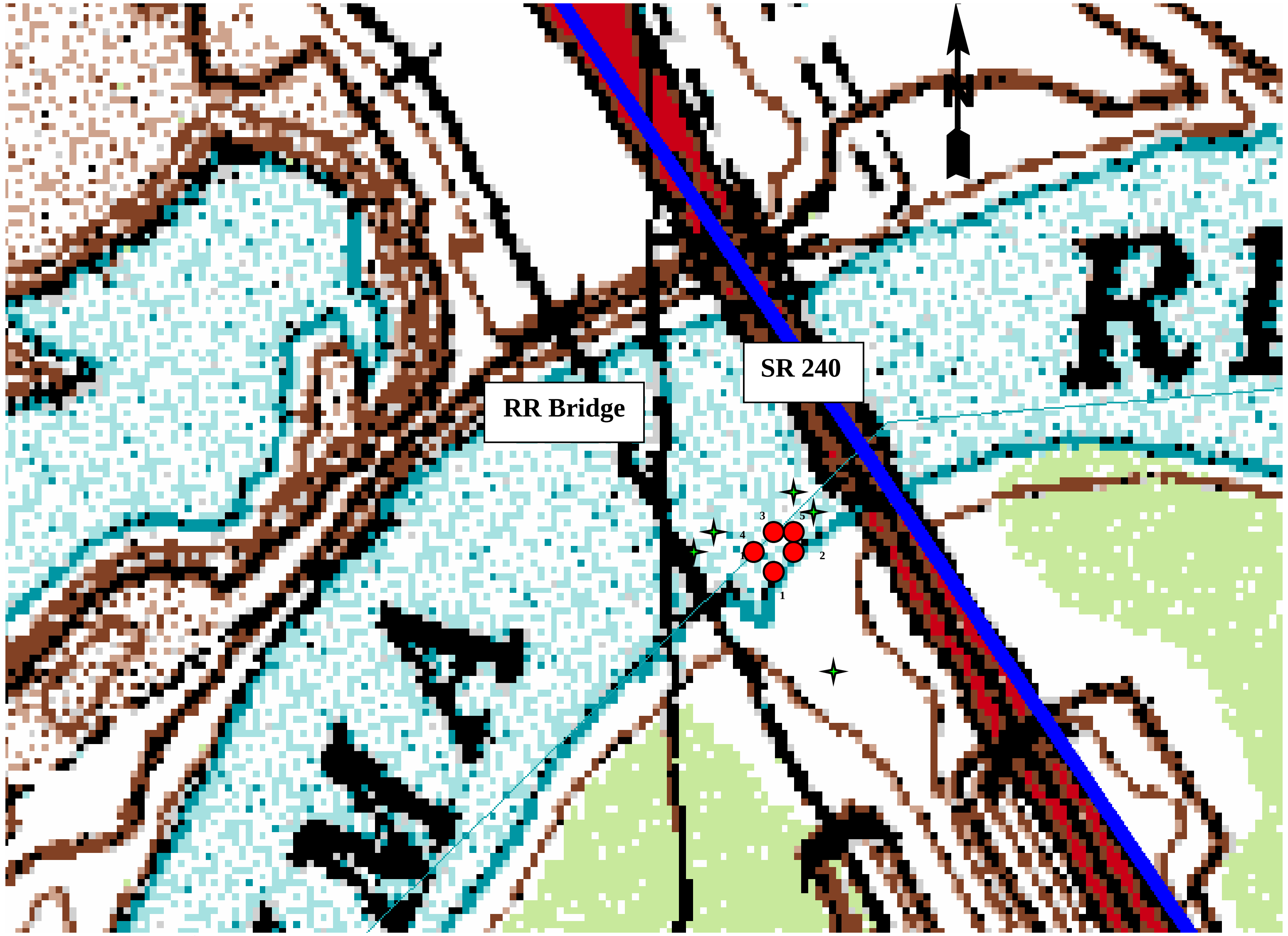
1. Located on the west side of the existing SR 240 bridge midway between that bridge and the railroad bridge two feet from the existing waterline on the riverbank in approximately one foot of water. Pile was driven on the east side of the temporary work trestle built to support the pile driver for the permanent pile driving.

2. Located on the west side of the existing SR 240 bridge midway between that bridge and the railroad bridge two feet from the existing waterline on the riverbank in approximately one foot of water depth. Pile was driven on the west side of the work trestle.

3. Located on the west side of the existing SR 240 bridge midway between that bridge and the railroad bridge two feet from the existing waterline on the riverbank in approximately 2.5 feet of water depth. Pile was driven on the east side of the work trestle.

4. Located on the west side of the existing SR 240 bridge midway between that bridge and the railroad bridge two feet from the existing waterline on the riverbank in approximately 2.5 feet of water depth. Pile was driven on the west side of the work trestle.

5. Located on the west side of the existing SR 240 bridge midway between that bridge and the railroad bridge two feet from the existing waterline on the riverbank in approximately 2.5 feet of water depth. Pile was driven on the east side of the work trestle adjacent to pile number 3.



✦ = Measurement locations. ● = Piles

Figure 3: Sound Level Measurement Locations

RESULTS

UNDERWATER SOUND LEVELS

Measurements were made by WSDOT for unattenuated pile driving on 2 separate days. Peak background sound levels ranged from 0.068 to 0.093 kPa (157 dB to 159 dB). During pile driving events, WSDOT measured underwater peak sound pressure levels ranging from 0.075 kPa to 0.432 kPa (158 dB to 173 dB) (Table 2). Measurements were made near the bottom (approximately 1 foot above bottom) and at mid-water level. For the first two piles mid-level measurements were made using the hand held sound level meter (waveform data were lost). The peak levels measured for the first two piles at mid-water and bottom depths ranged from 0.001 kPa to 0.009 kPa (123 dB to 139 dB). However, these values are suspect because they are below the background sound levels of 0.06-0.09 kPa (157 dB to 159 dB) and should not be used.

For piles 3, 4 and 5 measurements were made at 30, 90 and 30 feet respectively from the piles. For pile 3 the peak value was 0.431 kPa at mid level and 0.111 kPa at the bottom. There was a 0.321 kPa difference between the bottom and mid level measurements with the highest value measured at mid level. The peak values for the midwater and bottom measurements occurred at different time intervals. The waveforms for underwater peak impulse at 30 feet are shown in Figure 4.

Examination of the waveforms for pile number 3 indicate a moderate delay in rise time in pressure that occurs within the first 4 ms. A moderately rapid fluctuation in underpressure to over pressure occurs within about 1 ms. The decay time of the impulse is relatively slow, lasting about 50 ms. Much of the energy associated with the impulse occurs within the first 20 ms. There more than twice as much energy measured at midwater depth than near the bottom.

Figure 4: Time Traces of Pile Number 3 Peak Sound Impulses from Midwater (top) and Bottom (bottom)

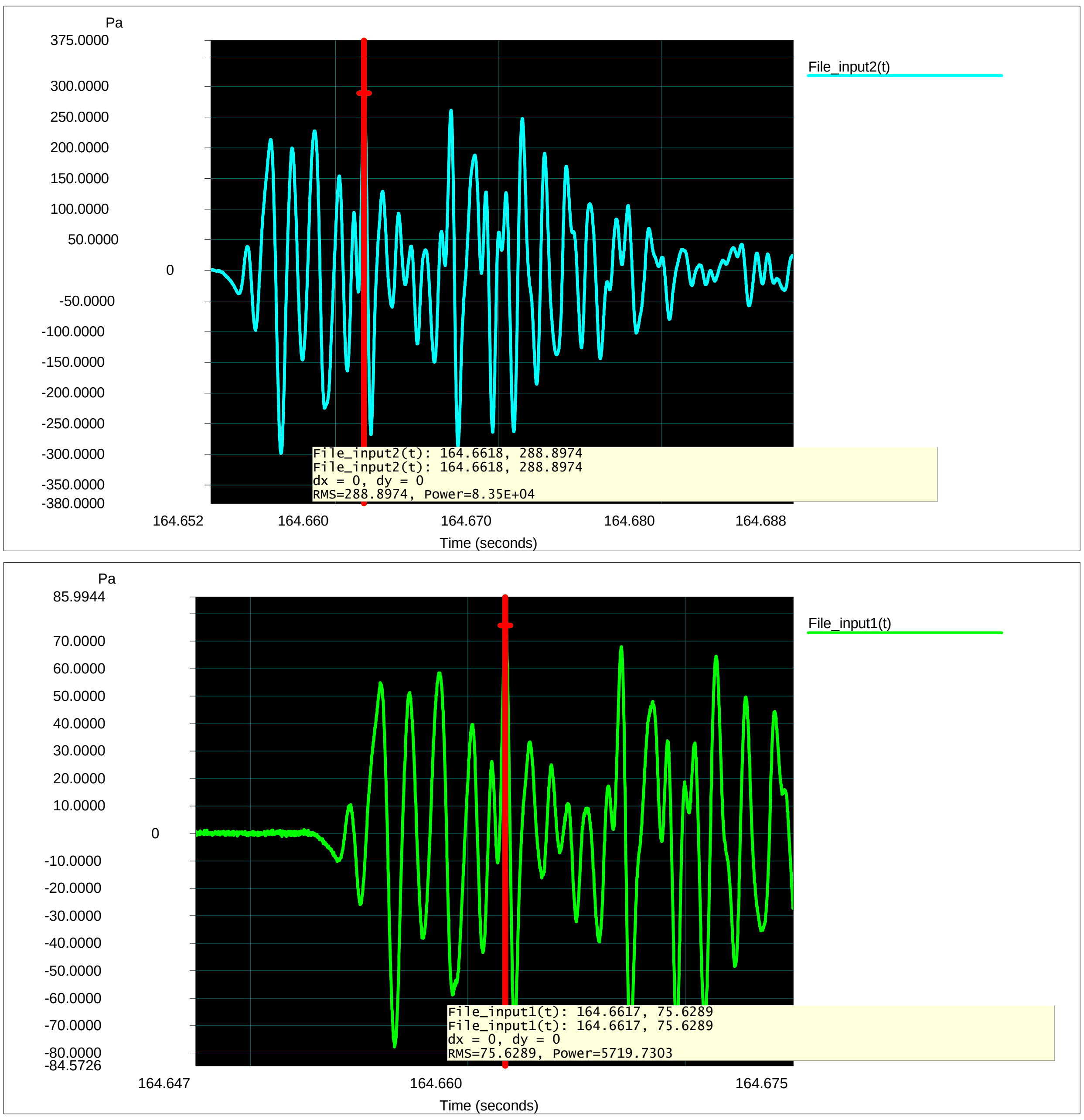
```
File_input2(t): 495.5676seconds, 431.8165Pa
File_input2(t): 495.5676seconds, 431.8165Pa
dx = 0seconds, dy = 0Pa
RMS=431.8165Pa, Power=1.86E+05Pa2
Overall RMS=84.0609Pa, Power=7066.2377Pa2
```

```
File_input1(t): 491.2596seconds, 111.3017Pa
File_input1(t): 491.2596seconds, 111.3017Pa
dx = 0seconds, dy = 0Pa
RMS=111.3017Pa, Power=1.24E+04Pa2
Overall RMS=29.1358Pa, Power=848.8937Pa2
```

For pile four the peak mid-water level was 0.288 kPa and the bottom level was 0.075 kPa. There was a 0.213 kPa difference between the bottom and mid level measurements with the highest value measured at mid level. The waveforms for underwater peak impulse at 90 feet are shown in Figure 5.

Examination of the waveforms indicate a moderate delay in rise time in pressure that occurs within the first 2 ms. A moderately rapid fluctuation in underpressure to over pressure occurs within about 1 ms. The decay time of the impulse is slow, lasting about 250 ms. Most of the energy associated with the impulse occurs within the first 30 ms.

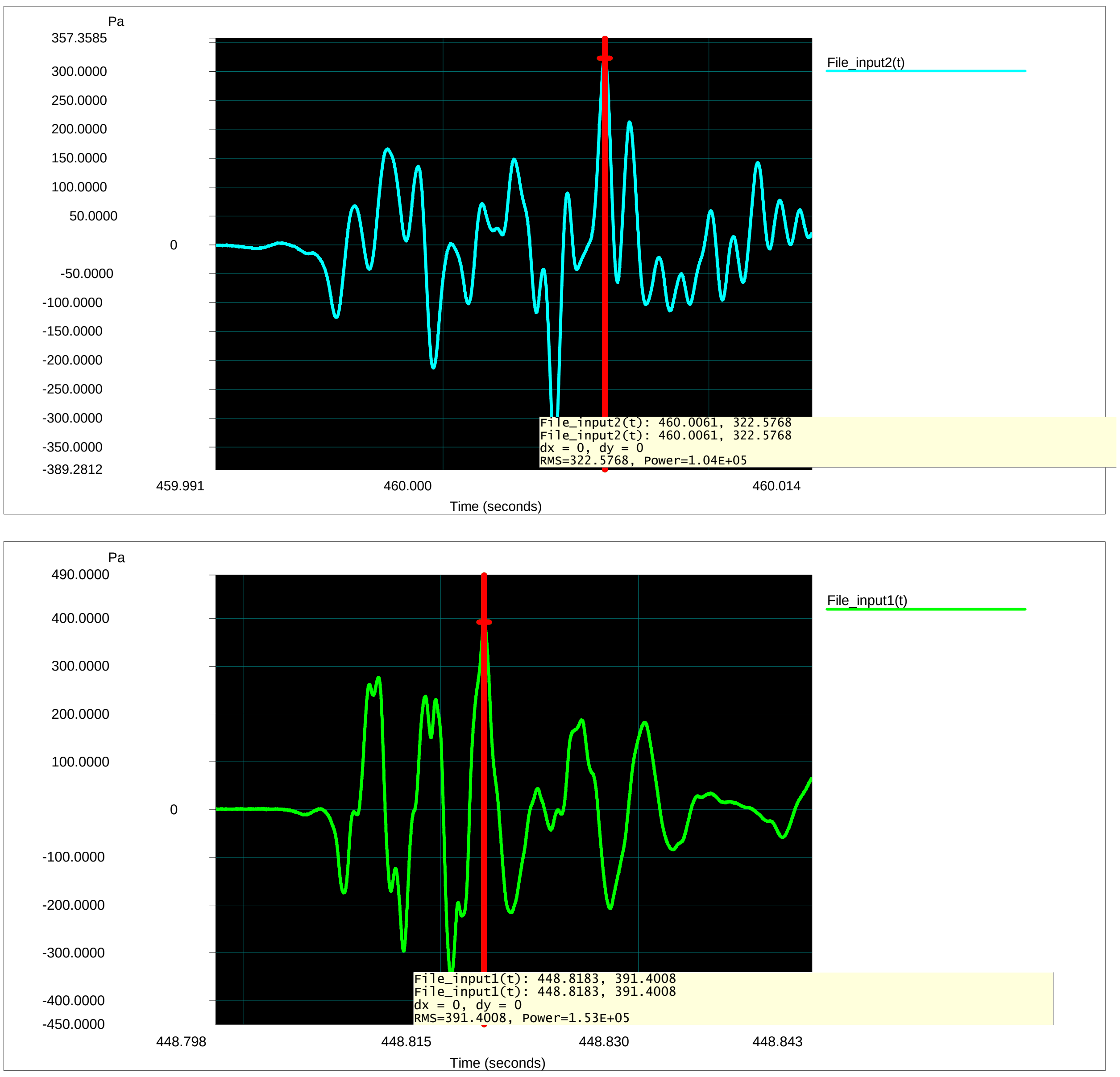
Figure 5: Time Traces of Pile Number 4 Peak Sound Impulses from Midwater (top) and Bottom (bottom)



Pile five had a peak value of 0.322 kPa at mid-water and 0.391 at the bottom. There was only a 0.069 kPa difference between the bottom and mid level measurements with the slightly higher value measured at the bottom level. The peak time trace of the pile driving is shown in Figure 6 below.

Examination of the waveforms indicates a delay in rise time in pressure that occurs within the first 12 ms. A moderately rapid fluctuation in underpressure to over pressure occurs within about 2 ms. The decay time of the impulse is slow, lasting about 425 ms. The peak values for both the midlevel and bottom occurred at slightly different time intervals. Most of the energy associated with the impulse occurs within the first 30 ms.

Figure 6: Time Traces of Pile Number 5 Peak Sound Impulses from Midwater (top) and Bottom (bottom)



```
File_input2(t): 460.0061, 322.5768
File_input2(t): 460.0061, 322.5768
dx = 0, dy = 0
RMS=322.5768, Power=1.04E+05
```

```
File_input1(t): 448.8183, 391.4008
File_input1(t): 448.8183, 391.4008
dx = 0, dy = 0
RMS=391.4008, Power=1.53E+05
```

The acoustical frequency content of underwater impulses is shown in Figure 7. The greatest acoustical energy was in the 0 to 100 Hz range and most energy was contained over the range of 0 to 1600 Hz.

Figure 7: Narrow Band Frequency Analysis

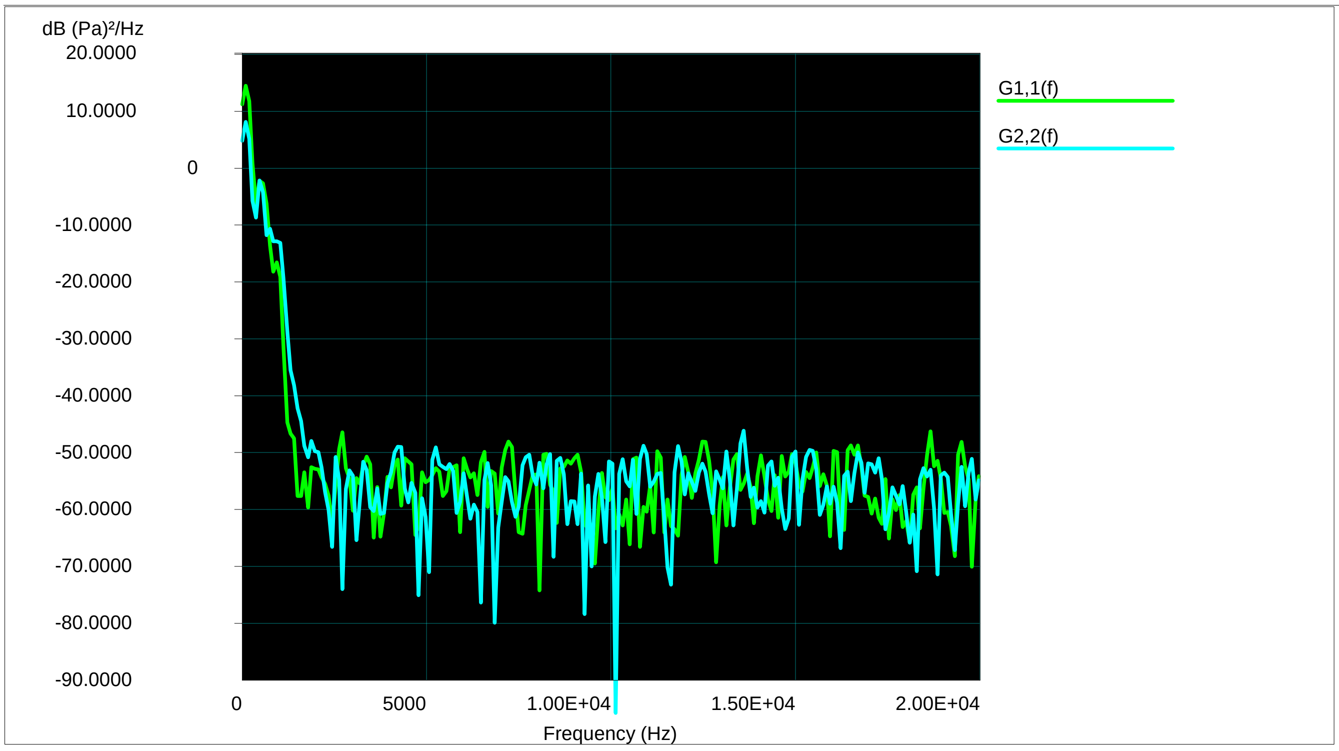


Table 2: Summary of Noise Measurement Results

		Sound Levels @ 30 ft. (kPa/dB)	Sound Levels @ 90 ft. (kPa/dB)		
Pile	**Water Depth (ft.)**	**Mid Depth[1]**	**Bottom Depth[2]**	**NOAA Limit (kPa)**	**Mitigation Measures**
1	5.3	0.001/120	0.003/130	75	None
2	2.7	0.002/126	0.009/139	75	None
3	2.5	0.432/173	0.111/161	75	None
4	2.5	0.288/169	0.075/158	75	None
5	2.5	0.322/170	0.391/172	75	None

1 – For pile #1 = 2.6 ft., for pile #2 = 1.4 ft., for piles #3, #4 & #5 = 1.2 ft.
2 – For pile #1 = 4.2 ft., for pile #2 = 1.8 ft., for piles #3, #4 & #5 = 1.4 ft.

WATER QUALITY

Water quality measurements were made in the field prior to and during the pile driving activity down stream of the site. Water quality parameters measured were water temperature, turbidity and pH. The results are shown in Table 3. There were no water quality differences found before or during pile driving activity.

Table 3: Summary of Water Quality Results

	Station	**Date[1]**	**Water Temperature (°F)**	**Turbidity (NTU)**	**pH**
Before	**SW1**	5/28/03	71.4	22.7	8.0
	SW2	5/28/03	73.2	18.4	7.8
	SW1	5/30/03	67.1	14.6	7.9
	SW2	5/30/03	70.3	12.6	8.1
During	**SW1**	7/7/03	78.8	10.7	8.6
	SW2	7/7/03	76.6	9.39	8.5
	SW3	7/7/03	77.5	8.60	8.6

[1] – 7/7/03 was a pile driving day, otherwise measurements were made prior to pile driving.

CONCLUSIONS

Driving of 16-inch diameter, open-ended steel piles generated sound levels that were non-lethal to fish. Without any mitigation measures to reduce underwater peak sound levels, sound levels ranged from 0.001 to 0.445 kPa at mid and bottom depths between 30 and 90 feet from the pile. Generally the highest sound levels were recorded at mid-water depth and at 30 feet from the pile.

It has been shown by other researchers that driving open-ended steel piles less than 18-inches in diameter would require monitoring but may not require mitigation dependent on the substrate that the pile is being driven through (Port of Vancouver, unpublished; Dr. Tom Carlson, unpublished). Since our piles were not being driven through bedrock, were only 16 inches in diameter, sound levels did not exceed 75 kPa and fish were observed jumping and feeding at the water surface before, during and after pile driving, it is apparent that driving 16-inch open ended steel piles has no impacts to wildlife.

Research conducted by the Port of Vancouver (unpublished) has indicated that it is not necessarily how high the peak is but rather how fast the peak is achieved (i.e. how fast is the rise time). The faster the rise time the greater the impacts to wildlife. Reyff et al., 2002 found that a delay in rise time greater than 1 ms will not produce impacts to wildlife. The rise times we measured were greater than 2 ms.

We recommend that future projects using open-ended steel piles 16-inches in diameter which are not being driven through bedrock should not require monitoring because the underwater sound levels they emit are orders of magnitude lower than the standards set by NOAA.

REFERENCES

Port of Vancouver, Unpublished.

Carlson, Thomas, Unpublished.

Reyff, James A., Paul P. Donavan and Charles R. Green Jr., 2002. Underwater Sound Levels Associated with Construction of the Benicia-Martinez Bridge. Preliminary results based on measurements made during the driving of 2.4 meter steel shell piles. Unpublished.