The Dalles Dam Fish Ladder Auxiliary Water System Vibration Monitoring: Methods

Preliminary only. October 17, 2017

1. Background

The U.S. Army Corps of Engineers is planning to modify the Fish Ladder Auxiliary Water System at The Dalles Dam in October 2017. To mitigate potential delay impacts to migrating salmonids associated with the planned construction work, vibration of the East Fish Ladder support columns in the vicinity of the excavation area will be monitored and recorded during construction activities.

The behavior of salmon in response to underwater sounds is still largely unknown. Salmon have relatively poor hearing with a sharp cut-off frequency of 380 Hz. Typically, salmon are sensitive to particle motion (bulk motion of water resulting from pressure wave propagation) rather than sound pressure (Hawkins and Johnstone 1978; Knudsen et al. 1992; Redford et al. 2012), so it is necessary to measure the particle motion in addition to sound pressure.

2. Field deployment

On October 5th, 2017, we deployed three identical measurement systems at three deployment sites (Figures 2-4). Each system will consist of a data acquisition system and sensors. To measure the particle motion in terms of acceleration in three (x-, y-, and z-) directions, three high-sensitivity (approximately 1000 mV/g) accelerometers (PCB Piezotronics model 393A03) were rigidly mounted in perpendicular directions (Figure 2). The three accelerometer cables were bundled and routed to a weatherproof enclosure. A solar power system (i.e., solar panel, charge controller, and at least one 12V battery) was located near each deployment site, with the solar panel mounted on a standalone structure that allowed the panel to be aimed toward the southern sky. The PCB Piezotronics model 393A03 accelerometers we used were designed to measure ultra-low amplitude, low frequency vibrations. They have a frequency range of 0.5 Hz to 2 kHz and a broadband resolution of 0.0001 m/s^2. All accelerometers were calibrated in the laboratory prior to field deployment. Monitoring commenced on October 5th and ran continuously until October 16th to develop baseline noise and vibration levels.

3. Threshold selection

Salmon are believed to be more sensitive to particle motion than sound pressure. Table 1 lists a literature synthesis of the avoidance response of juvenile salmon to infrasound. Knudsen et al. (1992) studied Juvenile Atlantic salmon in a pool and concluded that the particle acceleration at 5-10 Hz should be at least 0.01 m/s^2 to elicit an avoidance response. In a following study, they reported that a particle acceleration of 0.01 m/s^2 at 3 m deterred downstream migrating Atlantic salmon smolts in a river (Knudsen et al. 1994). Therefore, in our study, we selected 0.01 m/s^2 in the 5-10 Hz band as the threshold of acceleration magnitude, and evaluated the acceleration magnitudes calculated in each second referring to the 0.01 m/s^2 threshold.

Table 1: A literature synthesis of the avoidance response of juvenile salmon to infrasound (<20 Hz).

Researcher	Fish species	Test frequency	Location of study	Results
Knudsen et al. 1992	Juvenile Atlantic salmon	5, 10, 60 and 150 Hz	In a tube	The thresholds for awareness reactions were much lower at 5-10 Hz than at 150 Hz.
		10 and 150 Hz	In a pool	1. 10 Hz sound evoked avoidance response for fish within 2 m of the sound source. 2. The avoidance response threshold to 10 Hz sound was 10-15 dB above the spontaneous awareness reaction threshold. 3. At 5-10 Hz the particle acceleration should be at least 0.01 m/s^2 to elicit an avoidance response. 4. The 150 Hz sound failed to evoke avoidance response.
Knudsen et al. 1994	Juvenile Atlantic salmon	10 and 150 Hz	In a small river	Avoidance response to 10 Hz sounds was seen up to 3 m from the source, where sound intensity was about 0.01 m/s^2.
Knudsen et al. 1997	Juvenile spring chinook salmon and rainbow trout	10 Hz	In a tank	Initial tests always resulted in a strong flight response, but after three to four tests the fish more typically simply swam away as far as possible from the source. The avoidance response did not habituate even after 20 trials.
Mueller et al. (PNNL) 1998	30-70 mm rainbow trout and chinook salmon	7-14 Hz, 150, 180, and 200 Hz	In a tank	1. Juvenile salmonids, as small as 30 mm long, have infrasound detection capability when the particle motion exceeds $10^{-2} m/s^2$ at a frequency of 7-10 Hz. 2. A startle response in wild chinook salmon was observed when exposed to high-intensity (162 dB re 1 µPa), 150-Hz pure tone sound. 3. No observable effects were noted on hatchery chinook salmon or rainbow trout fry when exposed to 150, 180, or 200 Hz high-intensity sound. 4. Even for the maximum range at which acceleration measurement was made (4.2

				m), the local flow acceleration exceeded the minimum required for fish reactance (10^{-2} m/s^2).
Mueller et al. (PNNL) 1999	Juvenile chinook salmon, brook trout and rainbow trout	10 Hz	In a tank	1. Wild chinook salmon are much more likely to respond to 10 Hz infrasound than hatchery reared fish. 2. Rainbow trout fry showed no observable avoidance responses to infrasound, although a startle response was observed with 16% of the first five test exposures. 3. Test groups of eastern brook trout displayed the least behavior responses to the infrasound.

4. Data analysis

The rms particle acceleration in frequency band (5-10 Hz) was calculated in the following steps:

1) Convert raw data a_x, a_y, a_z to physical units according to the sensitivity of each accelerometer;
2) Calculate the acceleration magnitude with

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2};$$

3) Filter the particle acceleration magnitude (calculated from step 2) using a 5-10 Hz bandpass filter;
4) Calculate the Root Mean Square (RMS) of the bandpass filtered acceleration magnitude.

The selection of duration for the calculation can be important. To our knowledge, there is no standard on the method and duration selection. For our study, we plan to calculate the metrics for every second, minute, and hour. The calculated metrics will then be compared to dam operations and construction activities.

5. Spill decision criteria

If the construction activity is determined to affect fish migration in the fish ladder, spill will be required in the north side as a mitigation measure. The decision on where spill is required depends on the following factors:

- Literature suggested that 0.01 m/s^2 particle acceleration in frequency band (5-10 Hz) for downstream migrating juvenile salmon. It will be used for this study.
- Duration for over the threshold: Sustained, preferably in seconds or minutes?
- Any of the three monitoring locations.

6. Baseline monitoring (October 5th-16th, 2017)

The baseline accelerations at three locations were monitored from October 5th to October 16th, 2017 (Figure 5). The mean baseline (denoted by the magenta dash line) is highest at location 3 and lowest at location 1. Baseline accelerations at Location 2 have higher standard deviation than location 1 and 3. At location 2, an abrupt drop in rms acceleration is correlated with the shutdown of Turbine Unit 22 at 23:54:58, October 5th. In addition, an one-second spike exceeded the threshold at about 13:00, October 12th.

Table: Mean and standard deviation of baseline rms accelerations at three locations.

	Location 1	Location 2	Location 3
Mean (m/s^2)	0.0001	0.0007	0.0013
Standard deviation (m/s^2)	0.00005	0.0005	0.0004

References

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Figure 1: Construction site The Dalles Dam Fish ladder. The excavation area is marked with the black line numbered from 3 to 5.

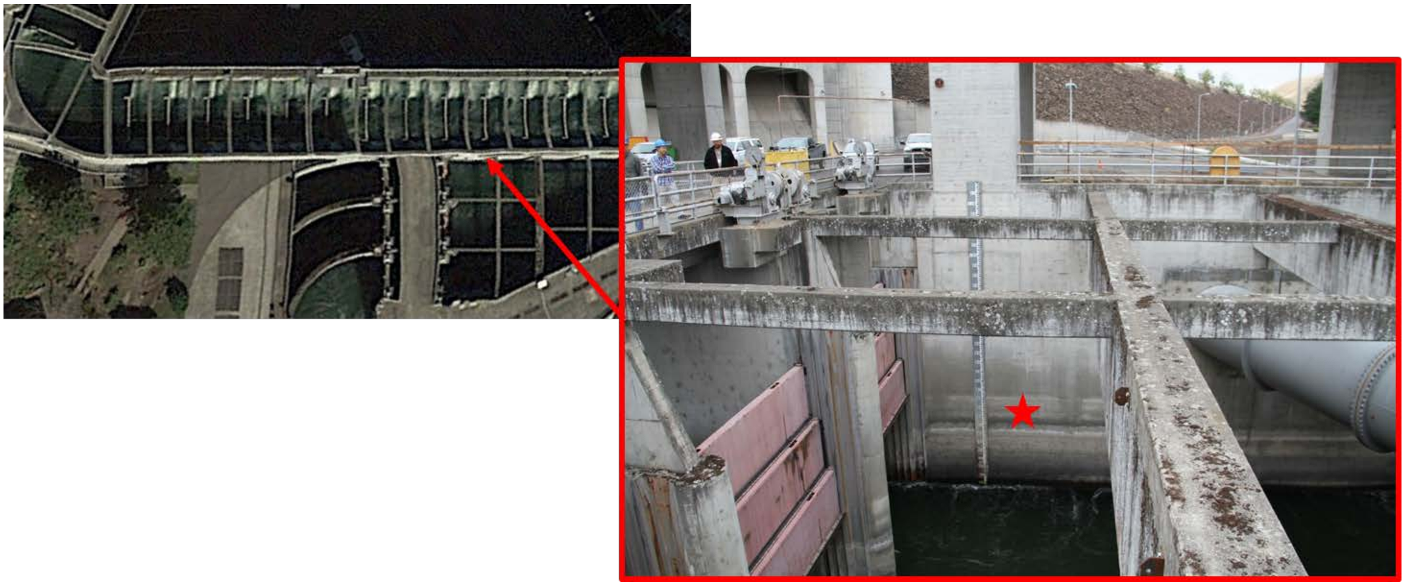

Figure 2: Deployment location #1, located at the entrance of the fishladder, on the side where the construction will occur. The accelerometers were attached to the inner wall of the fish ladder, above water.

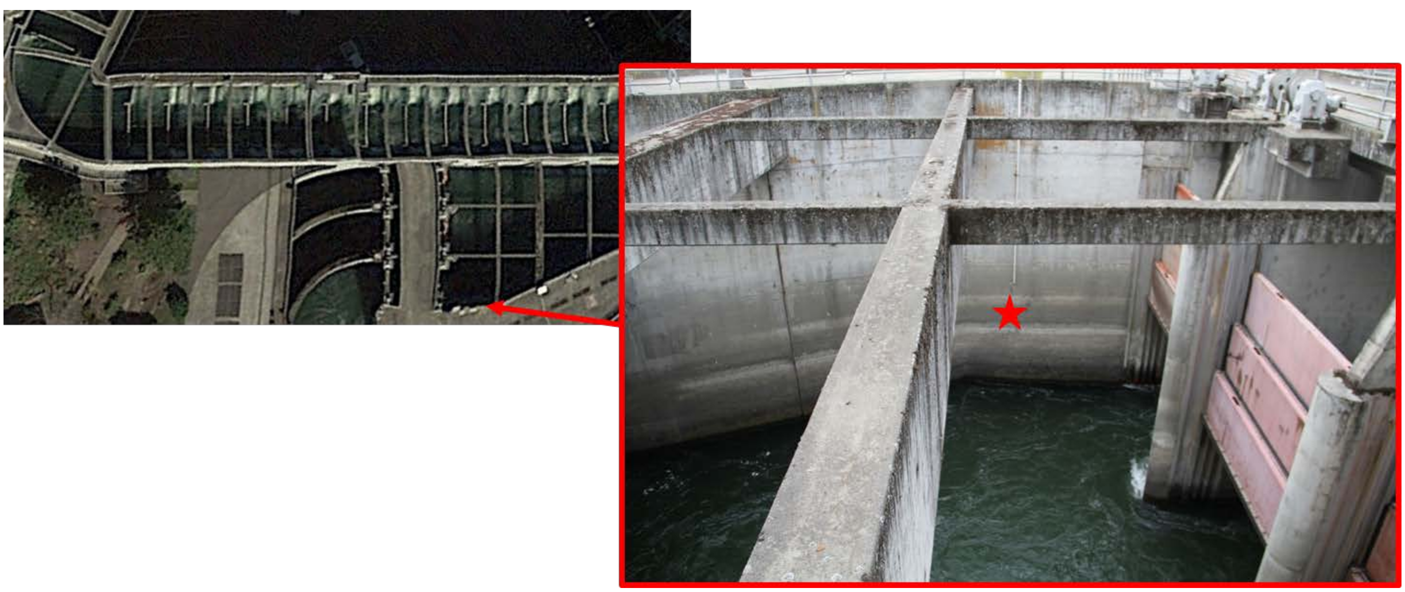

Figure 3: Deployment location #2, located on the opposite side of Location 2 at the entrance of the fish ladder. The accelerometers were attached to the inner wall of the fish ladder, above water.

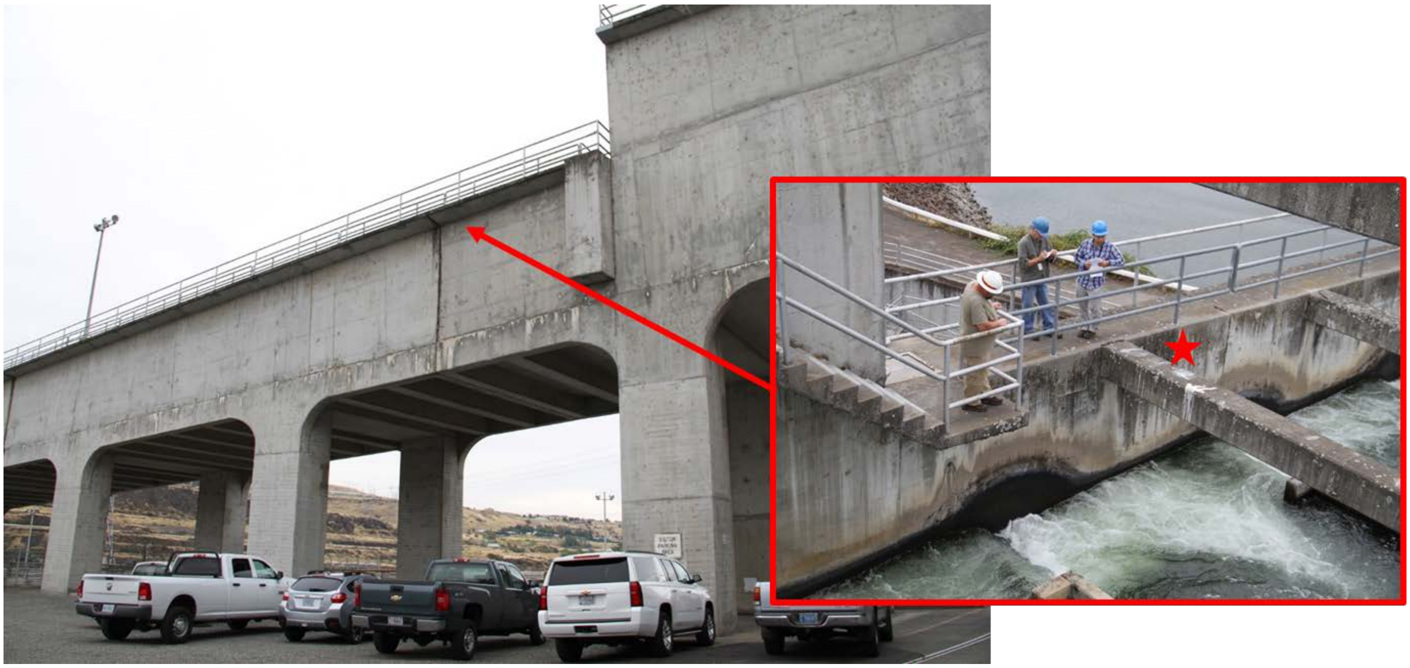

Figure 4: Deployment location #3, located at the upper site of the fishladder. The accelerometers were attached to the inner wall of the fish ladder, above water.

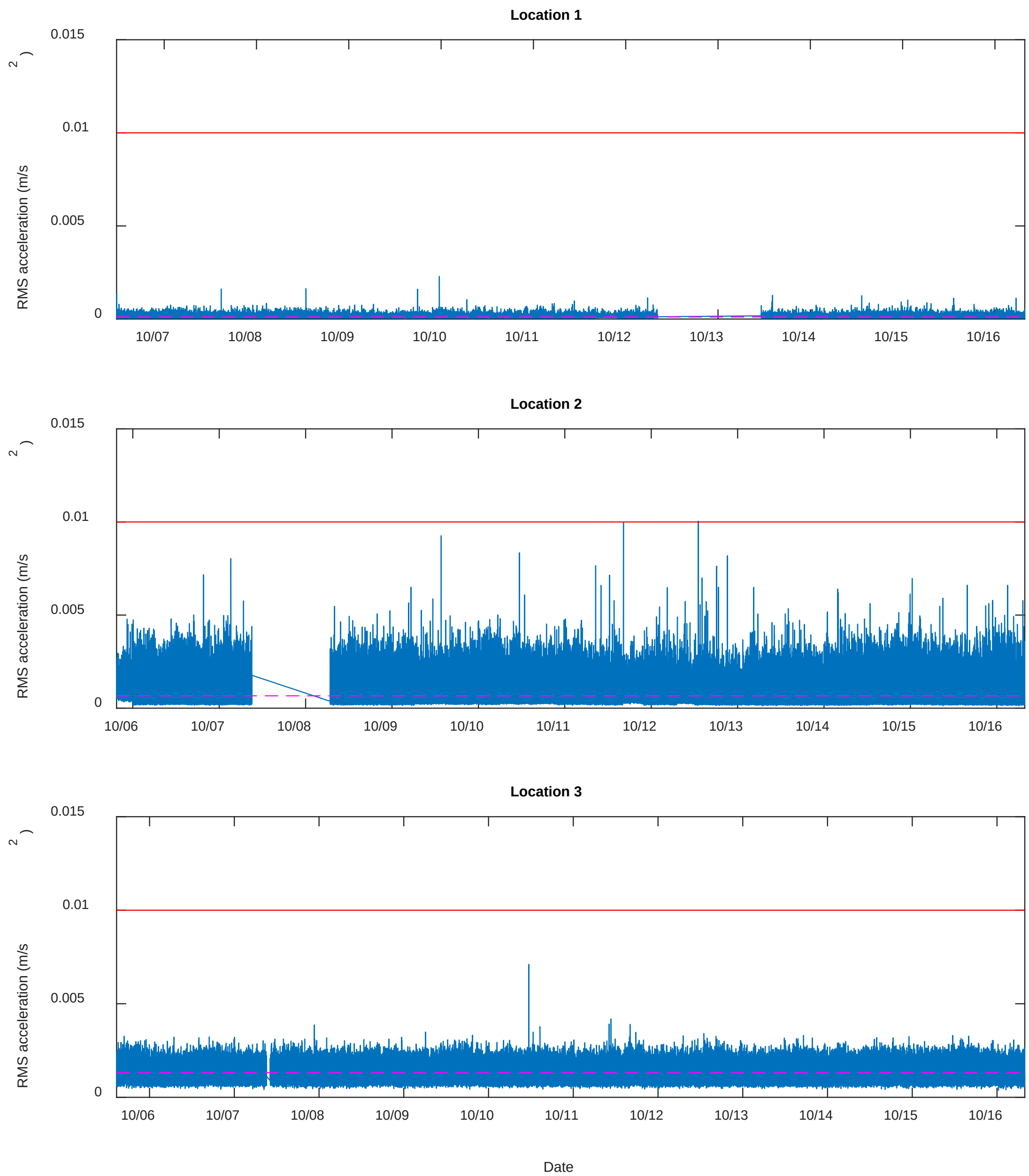

Figure 5: RMS particle accelerations at Location 1, 2 and 3 on October 5-16, 2017 (no construction activity). The magenta dash line represents the mean baseline rms particle acceleration at each location. The red line shows the 0.01 m/s^2 threshold of the rms particle acceleration.