ASSESSMENT OF THE IMPACTS OF UNDERWATER BLASTING ON FISHES NEAR THE NEW SOO LOCK

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Introduction: The Soo Locks on the St. Marys River, Sault Ste. Marie, Michigan, allow vessels to transit the 21 ft elevation change between Lake Superior and the lower Great Lakes. To accommodate larger vessels, a capital dredging event is scheduled to occur in 2021-2022 which will deepen the channel on the upstream side (west) of the new Poe lock. Underwater drilling and blasting may be required to fragment the rock for subsequent dredging. Blasting is expected to occur in dry within the Sabin Lock between the upstream and downstream cofferdams (out of water) to remove the existing concrete floor and underlying bedrock for new lock construction. The Michigan Department of Natural Resources (MDNR) is concerned about ground vibration and underwater shockwaves from the blasting and the potential physical impacts to nearby fish and fish eggs in the power plant tail race and the St. Mary's Rapids immediately north of the dredging site.

Objective: Conduct a literature review to determine the upper limit of substrate vibrations (as peak particle velocity [PPV; in/sec]) and water overpressures (psi) induced from blasting for estimating thresholds protective of fish spawning habitat in the immediate area. Of particular concern are blasting effects on the egg life stage of lake sturgeon (*Acipenser fulvescens*), lake whitefish (*Coregonus clupeaformis*) and Atlantic salmon (*Salmo salar*) that use the surrounding aquatic habitat to spawn.

Results: The results from the literature review were organized based on impacts to fish habitat from 1) substrate vibrations (in/sec), and 2) water overpressures (psi). We present threshold values based on a lethal dose that would cause an adverse effect on 1% (LD1) and 10% (LD10) of the population of fish. We also developed species sensitivity distributions (SSD) to estimate effects on fish eggs.

Impacts from Substrate Vibrations (as PPV, in/sec)

Sturgeon Eggs Literature Review

- The existing guidelines and data for the protection of spawning habitat and eggs from blasting effects are based on salmon and trout species (Wright and Hopky 1998; Jenson 2003; Faulkner et al. 2008; Timothy 2013). While lake whitefish is a member of the Salmonidae Family, no studies reporting blasting effects on sturgeon or whitefish eggs were found.
- Given the morphological and developmental similarities of sturgeon, salmon, and trout eggs, in terms of chorion (egg envelope) and epiboly development, **the existing data provide an adequate surrogate for predicting adverse risks from blasting to sturgeon eggs**.
- The existing guidelines for the protection of salmonid spawning habitat and fish eggs recommend not to exceed **2.0 in/sec** (Alaska guideline; Timothy 2013). Direct quotes from Timothy (2013) supporting this threshold value are as follows:
    - ''Peak particle velocities in spawning gravels are limited to no more than **2.0 in/s** during the early stages of embryo incubation before epiboly is complete.''

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  - "The 2013 blasting standard is based on 20 years of research and technological advances that provide accurate data on pressures and vibrations generated by an explosion. The standard is below levels that have been shown to cause injury or mortality to salmonids and salmonid embryos and provides a baseline for pressure and vibration monitoring that will aid Alaska Department of Fish and Game assessing the effectiveness of the standard to properly protect fish and embryos."

- Other relevant guidelines exist for blasting effects on fish eggs. The Canadian guidelines recommend a threshold of **0.5 in/sec** for salmon eggs (Wright and Hopky 1998). This threshold is considered **unnecessarily conservative** as this value includes a safety factor well over 10 (see supporting information below).

Observational Data of Egg Mortality

  - Blast simulation data indicate that peak particle velocity causing **10% mortality** (LD10) in **salmon eggs** range from **5.7 in/sec to 33 in/sec** (Jenson et al. 2003).
  - Blast simulation data indicate that peak particle velocity causing **10% mortality** (LD10) in **trout eggs** range from **49.4 to 69.1 in/sec** (Faulkner et al. 2008).
  - Field data exposed the eggs of lake trout to blasts from an open pit mine at Lac de Gras, Northwest Territories **found no egg mortality** at **1.1 in/sec** (Faulkner et al. 2006).
  - In a blast simulation, egg mortality increased in trout eggs (compared to control) in exposures greater than **5.2 in/sec** (Faulkner et al. 2008).

- Based on these data, an LD1 (1% mortality) of fish eggs would occur between the range of **1.1 in/sec** to **5.2 in/sec PPV**.

Species Sensitivity Distribution Analysis

- A species sensitivity distribution (SSD) was modeled using the existing blast effects data for egg sensitivities to the reported ranges of peak particle velocities (in/sec). SSDs can provide information regarding the relative sensitivities among species and the relative potency among species (proportion of total species affected with incremental increases in exposures) (Posthuma et al. 2002).

- Based on conservative estimates of reported LD10 (lethal dose at 10% of the population) using the **most sensitive stages** in egg development, 5% of the species tested are predicted have 10% egg mortality at **4.4 in/sec** (roughly **6 times greater** than the 0.75 in/sec threshold for the Fish Spawn Unit 10 area). See Attachment 1 for supporting data.

- Based on available data from **all egg developmental stages** from Jenson (2003) and Faulkner et al. (2008), 5% of the species tested are predicted to have 10% egg mortality at **34.1 in/sec** (roughly **45 times greater** than 0.75 in/sec threshold for Fish Spawn Unit 10 area). See Attachment 1 for supporting data.

Safe Distance Setback for Fish Eggs

- A safe setback distance was estimated for a range of peak particle velocity thresholds (in/sec) for protection of fish eggs based on scaled distance relationship to estimate peak particle velocity in rocky substrates. For example, a 25 kg charge weight would require a 59 meter setback distance to achieve a 0.75 in/sec threshold in a rocky substrate (Table 1). See Attachment 2 for supporting data.

Table 1. Safe setback distance (meters) from center of detonation of a confined explosive in rock substrates to achieve target thresholds for fish spawning habitat (modified from Wright and Hopky 1998).

Target PPV Threshold (in/sec) Fish Eggs	**Weight of Explosive Charge (kg)**							
	0.5	**1**	**2**	**5**	**10**	**25**	**50**	**100**
0.51	10.7	15.1	21.3	33.7	47.7	75.5	106.7	150.9
0.75	8.4	11.9	16.8	26.6	37.6	59.4	84.1	118.9
1.00	7.0	9.9	14.0	22.2	31.4	49.7	70.2	99.3
1.50	5.5	7.7	10.9	17.2	24.4	38.5	54.5	77.1
2.00	4.6	6.4	9.1	14.4	20.4	32.2	45.5	64.4
4.00	3.0	4.2	5.9	9.3	13.2	20.9	29.5	41.8
6.00	2.3	3.2	4.6	7.2	10.2	16.2	22.9	32.4

Impacts from water overpressures (as psi)

Estimating effects from dry blasting to fish populations

- The potential impacts from dry blasting to the local fish population are dependent on a number of site specific factors ranging from the blasting details (type and amount of explosive charge, location and depth in the substrate, water depth, substrate type, charge delay, confinement, etc.) and morphology of the fish species (e.g., presence/ absence of swim bladder, size).
- Based on the known details of the Soo Locks blasting plans, using dry blasting (out of the water) will effectively **minimize the overpressure** to species occurring in the water column (sudden change in water pressure from ambient), which is the primary mechanism for causing injury to fish.
    - Shock waves generated by **in-water blasting have greater lethal effects as compared those propagated from ground to water** due to the sharper pressure-time signature (peak overpressure). For dry blasting, part of the blasting energy is reflected and lost at the ground-water interface (ADFG 1991).
- The Alaska guideline (Timothy 2013) recommends:
    - "The instantaneous pressure rise in the water column in rearing habitat and migration corridors is limited to no more than **7.3 psi** where fish are present"
- Other commonly reported in-water psi guidelines for the protection of fish habitat are **2.7 psi** (Baird and Roberson 1984) and **14.5 psi** (Wright and Hopky 1998).
- Safe distance setbacks have been proposed in the literature for the protection of aquatic life in fish-bearing waters for dry blasting (ADFG 1991). Estimations are used to describe transfer of shock pressure from the substrate to the water (see spreadsheet). For example, safe setback distances for 11.3 kg (25 lb charges) are 52 meters (172 ft) for rock substrates based on a 2.7 psi threshold (Table 2). See Attachment 2 for supporting data.

Table 2. Dry blasting safe setback distance (meters) from anadromous fish based on 2.7 psi threshold. Note: Scaled distance relationship of single shot of given weight explosive from a straight line distance to the water body. (source: ADFG 1991)

Substrate Type	Weight of Explosive Charge (kg)					
	0.45	**0.9**	**2.3**	**4.5**	**11.3**	**45.4**
Rock	10	15	23	33	52	105
Frozen Soil	10	14	22	31	49	98
Ice	9	12	20	28	44	88
Saturated Soil	9	12	20	28	44	88
Unsaturated Soil	9	9	14	19	30	61

- The results of the literature review found two additional studies of interest. General observations from these underwater blasting studies are as follows:
  - Carlson et al. (2019) indicate that an LD1 (1% mortality of population) range from 1 to 35.1 psi-ms for adult chum salmon (*Oncorhynchus keta*).
  - Reported in-water blasting from Wilmington Harbor, NC using **52.9 to 61.7 lbs** charges observed an **LD1 (1% mortality) of juvenile shortnose sturgeon (*Acipenser brevirostrumat)* 140 ft radius** from the blast (USACE 2000).

Conclusions and Recommendations

- Based on the results from the literature review, these data indicate that **1 in/sec is below the LD1** level for fish eggs and would be sufficiently protective of fish spawning habitat. A 0.75 in/sec is more conservative than that required for protection of eggs and larvae.
- Dry blasting is expected to avoid or drastically minimize water overpressures (as psi) and therefore minimize or avoid impacts to the larval and adult fish present in the spawning areas.

References Cited (Report and Supplemental Spreadsheets [Attachment 1 & 2])

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