Sensory Deterrent Systems

U.S. ARMY CORPS OF ENGINEERS **Building Strong®**

ANS Control: Sensory Deterrent Systems – Acoustic Air Bubble Curtains, Electrical Barrier, Underwater Sound, and Underwater Strobe Lights

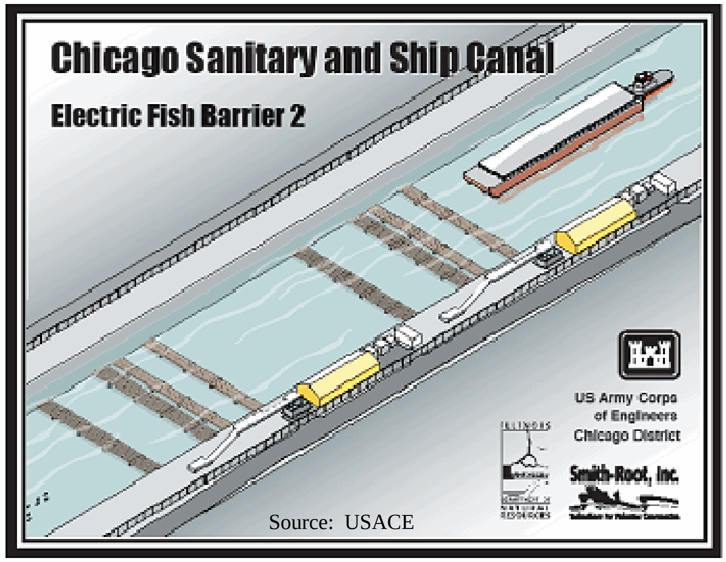

Illustration of Electrical Barriers and submerged electrical arrays within the Chicago Sanitary and Ship Canal, located in Romeoville, IL

Targeted Species: Sensory deterrent systems are used to prevent the upstream movement of fish; specific ANS of Concern – CAWS[1] that may be controlled through use of these technologies include alewife (*A. psuedoharengus),* bighead carp (*H. nobilis),* black carp (*Mylopharyngodon piceus),* blueback herring *(Alosa aestivalis),* inland silverside (*Menidia beryllina),* lamprey (*Petromyzon marinus),* ruffe (*Gymnochephalus cernnus),* northern snakehead (*Channa argus),* sea and tubenose goby (*Proterorhinus marmoratus*), silver carp (*Hypophthalmichthys molitrix),* skipjack herring (*A. chrysochloris),* and threespine stickleback (*Gasterosteus aculeatus).*

Selectivity: This technology was designed to control or manage fish. It is non–selective and cannot target specific fish ANS of Concern – CAWS.

Developer/Manufacturer/Researcher: These technologies are available through a variety of manufacturers.

Brief Description: Locating an effective and economical way to influence fish behavior and movement is one of the main challenges in fish management. Several technologies that attempt to elicit fish movement have been explored, and are collectively referred to as sensory deterrent systems.

Acoustic Air Bubble Curtains – This system can be deployed in much the same way as a standard air bubble curtain, but its effectiveness as a fish barrier is potentially enhanced by the addition of a sound signal. Bubble curtains are walls of bubbles rising from a bottom-resting bubbler manifold (perforated pipe) supplied with compressed air. Bubble curtains have been used for many years to protect fish from the effects of pressure waves created by explosions from underwater construction (Keevin & Hempen 1997). When used with sound at an effective frequency, bubble curtains can contain and amplify sounds that repel some species of fish (Kuznetsov 1971; Hocutt 1980).

Electric Barrier – Electric barriers use an electrical stimulus to alter fish behavior. There are three electrical barriers in the Chicago Sanitary and Ship Canal that span the width of the waterway with a series of electrodes. These electrodes emit pulsed DC charges into the water at a rate of up to 2.3

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

volts/inch, 30 hertz and 2.5 milliseconds. Depending upon strength of the field, electric barriers can be used to deter, stun, or kill the organism. The reactions of fish to electrical exposure is often size and species dependent (Bird & Cowx 1993). Electric barriers are most effective against actively swimming organisms rather than planktonic organisms that float in the water column. A stunning strength field would work best if the only organisms involved were swimming upstream. If the organism encountered the field and failed to turn away, it would be stunned and washed downstream, whereas a downstream moving organism would be stunned and washed through the barrier. A deterring electric field would deter fish or other actively swimming organisms from passing upstream or downstream through the field (USACE 1999).

Underwater Sound – This type of sensory deterrent system uses underwater sound (projectors powered by audio amplifiers and electronic signal generators) to create a repellent acoustic field, comprised of near- and far-field sound components. The near-field sound component is primarily caused by water particle vibration; the far-field sound component, located further from the sound source, is caused by pressure. The combination of near- and far-field sound displacement may be useful as a deterrent system because fish use sound to orient themselves in their surrounding environment. Depending on the type of sound system, frequencies range from 20 to 500 Hz, under varying amplitudes.

Underwater Strobe Lights – Strobe lights are a widely used type of lighting for fish control. Strobe lights produce flashes of light at rapid rates, depending on the target species and scale of the water body and light installation. Large scale systems commonly consist of four individual lights that flash at a rate of 450 flashes/minute, and have an approximate light intensity of 2634 lumens/flash. This type of system uses xenon gas tubes, which emit broad spectrum white light. Small scale systems can consist of an individual cylindrical strobe light (0.16 m length by 0.04 m diameter) with a flash rate of only 86 flashes/minute. Both systems have been shown to alter fish movements in both experimental and field settings for a variety of fish species.

Prior Applications: Air bubble curtains (Patrick et al. 1985; Welton et al. 2002); and combinations thereof have been successful in altering fish behavior (Amaral et al. 2001); underwater sound (Popper & Carlson 1998; Goetz et al. 2001; Mueller et al. 2001; Sand et al. 2001); underwater strobe lights (Patrick et al. 1985; Sager et al. 1987; Konigson et al. 2002; Richards et al. 2007; Hamel et al. 2008).

Acoustic Air Bubble Curtains – Ruggles (1991) reported that air bubbles are an effective control for some saltwater species, and possibly for other species in streams and small rivers. Patrick et al. (1985) reported that air bubbles produced avoidance behavior in laboratory experiments with gizzard shad *(Dorosoma cepedianum)*, alewife, and rainbow smelt, and that avoidance increased when air bubbles were combined with strobe lights. Acoustic bubble curtains have been used experimentally to guide salmon movements on the San Joaquin River (Science News 2009). While the basis for the response was not known, it may have been a visual stimulus or the sound associated with the bubbles, as suggested by Kuznetsov (1971).

Electric Barrier – Electric fields were initially applied in North America in large scale to prevent the upstream movements of sea lamprey in the Great Lakes basin in the 1950s. By 1960, electric barriers were installed in 132 tributaries of the Great Lakes. However, lamprey control measures did not become truly effective until after 1958 when a selective toxicant - the lampricide 3-trifluoromethyl-4-nitrophenol (TFM) - was used to destroy larval lampreys in streams (Smith & Tibbles 1980). Electrical barriers have been used to protect lakes from common carp and bigmouth buffalo (Verrill & Berry, Jr. 1995). The U.S. Army Corps of Engineers operates three electrical barriers on the Chicago Sanitary and Ship Canal near Romeoville, Illinois, to prevent Asian carp species from transferring from the Mississippi River Basin into the Great Lakes Basin.

Underwater Sound – Both laboratory and field tests have been performed on acoustic systems. For example, a study was conducted to evaluate an infrasound (<35 Hz) acoustic fish fence designed to guide downstream migrating European silver eels *(Anguilla anguilla)*. The result indicated a significant shift of the migrating eels away from the infrasound source (Sand et al. 2001). In a similar study, experimental tests were conducted to evaluate behavioral responses of chinook salmon to infrasound, including both hatchery-reared and wild juvenile fish. Both wild juvenile chinook salmon (40-45 mm) and hatchery-reared chinook salmon (45-50 mm) showed avoidance responses when exposed to a 10 Hz source (Mueller et al. 2001). In addition, Gibson and Myers (2002) reported positive results for a fish diversion system that utilized high-frequency sound (122-128 kHz) at the Annapolis Royal Generating Station, upstream of Annapolis Royal, Nova Scotia, Canada. The effectiveness of the diversion system was evaluated by monitoring fish passage through the turbine and two adjacent fishways; the rates of passage of American shad *(Alosa sapidissima)* and alewife through the turbines decreased by 42% and 48% respectively.

Underwater Strobe Lights – Nemeth and Anderson (1992) evaluated the effects of strobe lights on juvenile coho salmon *(Oncorhynchus kisutch)* under controlled conditions and found that smolts[2] typically hid when subjected to lights. Similarly, Maiolie et al. (2001) reported an 80% reduction in density of kokanee *(O. nerka)* within a 30 meter radius when the fish were subjected to a field application of strobe lights. Richards et al. (2007) found largemouth bass *(Micropterus salmoides)*, chinook salmon *(O. tshawytscha)*, yellow perch *(Perca flavescens)*, and channel catfish *(Ictalurus punctatus)* all elicited an avoidance response to strobe lights in an experimental setting. Additionally, Hamel et al. (2008) reported that rainbow smelt *(Osmerus mordax)* were repelled to a horizontal distance of 15 meters when subjected to underwater strobe lights in a clear water reservoir.

General Effectiveness: Overall, the applicability of sensory deterrent systems across species or across varying environmental or physical conditions and of different ages and sizes of organisms is not well understood (Coutant 2001).

Acoustic Air Bubble Curtains – The effectiveness of an acoustic air bubble curtain depends on several factors, including flow, background noise, and source interactions. Taylor et al. (2005) reported that an acoustic air bubble curtain was 95% effective at holding back bighead carp when tested in a raceway. Overall, little work has been done with bubble barriers relative to other sensory deterrent systems. The work that has been completed does not appear to have been broadly successful in influencing fish behavior or movements.

[2] A smolt is a juvenile salmon in the stage of migrating from fresh water to the sea.

Electric Barrier – Electrical barriers have been shown to be effective for a wide range of fish species and fish sizes (Palmisano & Burger 1988; Swink 1999; Holliman 2010). However, the complexity of electrical barrier systems and the intricacies involved in operation and monitoring may always preclude absolute effectiveness (Stokstad 2003; Clarkson 2004).

Underwater Sound – Unlike underwater strobe lights, sound is a good candidate for an effective control technology because it has few limitations in water. Sound is especially effective when used over long distances, or when visibility is marginal. Sound travels at high speed through water and attenuates in all directions. The critical issue that remains to be determined is how well a particular species can detect a signal with the inner ear and/or lateral line (Popper & Carlson 1998).

Underwater Strobe Lights – The overall rate of effectiveness of underwater strobe lights depends on a number of variables, including species, age, physiological condition, and environmental conditions (Popper & Carlson 1998). The transmission of light in water is affected by water quality characteristics. Concentrations of inorganic suspended solids, chlorophyll *a*, and detritus can affect light absorption and scattering, thereby influencing light attenuation. The effectiveness of strobe lights in water also varies depending on time of day. During daytime hours, background illumination often fades out light from the stimulus, making it less effective; at night, ambient light is low and the strobe lights are more efficient (Electric Power Research Institute 1994). In addition to water clarity, the rate at which fish are deterred is dependent on the target species. Species vary in their response to a light stimulus; for some it may act as an attractant, while for others it acts as a deterrent, even if two species are found in the same habitat (Brett & McKinnon 1953; Feist & Anderson 1991). Brett and McKinnon (1953) demonstrated this behavior in an early study of sealed beam lights. When subjected to the light source, some fish species swam toward the light, while others were repelled. As Hamel et al. (2010) noted, however, this response could be due to a concentration of prey (e.g., zooplankton) and/or an increase in feeding efficiency for visual-feeding fish.

Aforementioned data indicates that it is not clear whether strobe light illumination is an effective control method for all species or all ages of a particular species (Patrick 1982). As Anderson (1988) discussed, without data on the behavioral responses of different species to strobe illumination, it will not be possible to design proper lighting systems or to ensure that the fish will be influenced.

Operating Constraints: The main operating constraints in implementing sensory deterrent systems include flow field conditions, environmental and physical conditions at study sites, cost, scale, and site-specific characteristics. Due to the varying width and depth of a natural stream or river, such a deterrent barrier would need to cover a much wider cross section than just the main river channel; otherwise, ANS may bypass the barrier during high flow conditions. Frequent repair or replacement of underwater equipment for sensory deterrent barriers in channels is anticipated, due to the harsh environment, including floating ice, debris, shifting sand and gravel banks, and boat traffic.

Cost Considerations:

Implementation: Implementation costs for each of the sensory deterrent systems will vary depending on site-specific characteristics, location, scale, and construction and equipment requirements. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: All deterrent systems require electricity and routine maintenance. A performance monitoring program would be required for each sensory deterrent system.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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