PSEG Nuclear LLC
P.O. Box 236, Hancocks Bridge, NJ 08038

SEND VIA EMAIL

September 25, 2020
LR-E20-0097

Briana A. Grange
Conservation Biologist & ESA Consultation Coordinator
U.S. Nuclear Regulatory Commission
Environmental Center of Expertise
Office of Materials Safety and Safeguards
Washington, DC 20555-0001

Dear Ms. Grange:

SALEM GENERATING STATION
DOCKET NOS.: 50-272 AND 50-311
RE-INITIATION OF SECTION 7 CONSULTATION
BIOLOGICAL & ENGINEERING EVALUATION OF ALTERNATIVES

As previously discussed with the U.S. Nuclear Regulatory Commission (NRC) and the National Marine Fisheries Service (NMFS), and as referenced in the NRC request for re-initiation of the Section 7 Consultation[1], PSEG committed to conduct a biological and engineering evaluation of technologies and operating measures (TOMs) that may potentially reduce adverse effects associated with impingement of sturgeon at Salem Generating Station Units 1 and 2 (Salem). The evaluation is now complete and a copy of the report has been enclosed for your information and use.

Available literature and best professional judgment were used for the selection and design of applicable TOMs. Based on results of the biological and engineering evaluation, PSEG proposes implementation of the measures described below in Table 1 to potentially reduce incidental take of sturgeon. Given the many variables that effect incidental take, the actions would be initiated using a phased approach that

[1] Biological Assessment of Impacts to Atlantic Sturgeon and Its Designated Critical Habitat for Salem Nuclear Generating Station, Unit Nos. 1 and 2, Continued Operation Under Renewed Facility Operating License Nos. DPR-70 and DPR-75, July 2020, https://www.nrc.gov/docs/ML2015/ML20156A068.pdf

evaluates the effectiveness of the proposed mitigative methods before proceeding to the next phase. PSEG would submit summary reports for each phase and consult with the respective agencies to determine whether additional actions are warranted. Each phase includes pilot testing and monitoring to ensure that PSEG is taking appropriate steps to minimize impacts to and otherwise protect sturgeon. PSEG is committed to reducing the incidental take of sturgeon at the Salem circulating water intake structure and would welcome an opportunity to discuss these proposed measures and phasing with the NMFS and the NRC.

Should you or your staff have any questions on this matter, please feel free to contact Ken Strait, Manager - Biological Programs at kenneth.strait@pseg.com.

Sincerely,

Charles V. McFeaters
Site Vice President - Salem

Enclosures (1)

Table 1. Proposed measures to be implemented to reduce incidental take of sturgeon

	Action	Description	Date	Duration	Evaluation
Phase 1 (Items #1 through #4 assumed to continue after consultation with NMFS)					
#1	Increased frequency of trash rack cleaning	Frequency of trash rack cleaning will be increased to minimum of 2X/wk during period of peak sturgeon abundance regardless of operational needs	12/1/2020	December 1st through April 30th	Summary report evaluating effectiveness to be submitted to NMFS after completion of Phase 1
#2	Delayed closing of trash rake gripper	Closing of the trash rake gripper after lowering to debris level will be delayed a minimum of three (3) minutes during period of peak sturgeon abundance	12/1/2020	December 1st through April 30th	Summary report evaluating effectiveness to be submitted to NMFS after completion of Phase 1
#3	Optimized installation period for ice barriers	Later installation and earlier removal of the ice barriers; PSEG will conduct an analyses of long-term river water temperature data to determine minimum period when ice barriers need to be installed	12/1/2020	Annual	Summary report evaluating effectiveness to be submitted to NMFS after completion of Phase 1
#4	Hydroacoustic monitoring of trash bar condition & cleanliness	Annual inspection of trash bars using hydroacoustic monitoring to assess conditions	12/1/2020	Annual	Summary report evaluating effectiveness to be submitted to NMFS after completion of Phase 1
#5	Pilot testing of low frequency sound deterrent device	Pilot testing of deck-mounted sound deterrent device deployed into individual intake bays	3/1/2021 3/1/2022	30 days each year or as required to complete testing	Summary report evaluating effectiveness to be submitted to NMFS after completion of Phase 1
#6	Phase I Report	Summary Report on Phase I Effectiveness	8/1/2023		Consultation with NMFS following submittal of Phase 1 Report; decision on need for Phase 2 actions
Phase 2 (Dependent on effectiveness of Phase I actions & after consultation with NMFS)					
#7	Seasonal deployment of low frequency sound deterrent device	Seasonal deployment of deck-mounted sound deterrent device into individual intake bays in conjunction with trash raking	12/1/2023	December 1st through April 30th for three years	Summary report evaluating effectiveness to be submitted to NMFS after completion of Phase 2
#8	Pilot testing of hydroacoustic monitoring during trash raking	Pilot testing of deck-mounted hydroacoustic monitoring into individual intake bays during trash raking to detect presence of sturgeon in vicinity of trash bars	3/1/2024 3/1/2025	30 days each year or as required to complete testing	Summary report evaluating effectiveness to be submitted to NMFS after completion of Phase 2
#9	Phase 2 Report	Summary Report on Phase 2 Effectiveness	8/1/2025		Consultation with NMFS following submittal of Phase 2 Report; decision on need for Phase 3 actions
Phase 3 (Dependent on effectiveness of Phase 2 actions & after consultation with NMFS)					
#10	Seasonal deployment of hydroacoustic monitoring during trash raking	Seasonal deployment of deck-mounted hydroacoustic monitoring into individual intake bays during trash raking to detect presence of sturgeon in vicinity of trash bars	12/1/2025	December 1st through April 30th for three years	Summary report evaluating effectiveness to be submitted to NMFS after completion of Phase 3
#11	Phase 3 Report	Summary Report on Phase 3 Effectiveness	8/1/2028		Consultation with NMFS following submittal of Phase 3 Report

C Julie Crocker, NMFS, Endangered Fish Recovery Branch Chief (via email)
Lynn Lankshear, NMFS, Atlantic Sturgeon Coordinator (via email)

Solving flow problems since 1894

Final Report

Evaluation of Potential Technologies or Operational Measures for Reducing Incidental Takes of Sturgeon at Salem Generating Station

Prepared for

PSEG Nuclear LLC

Report – Revision 01

Prepared by

ALDEN Research Laboratory, Inc

September 23, 2020

Table of Contents

List of Figures

List of Tables

1.0 Introduction

Atlantic and Shortnose sturgeon (*Acipenser oxyrhynchus* and *A. brevirostrum*) occurring in the Delaware River and Estuary in the vicinity of SGS are federally-listed endangered species. As such and pursuant to the Endangered Species Act (ESA), the National Marine Fisheries Service (NMFS) issued a Biological Opinion (BiOp) in 2014 for potential effects of SGS and the Hope Creek Generating Station on the affected populations of each species, as well as three species of listed sea turtles. The BiOp includes an Incidental Take Statement (ITS) that exempts certain takes of listed sturgeon and turtles impinged or captured during the operation of either station for the remainder of the new license terms. Subsequent to the BiOp, the Nuclear Regulatory Commission (NRC) issued amendments to the renewed facility operating licenses for both stations stipulating that PSEG shall adhere to the specific requirements of the BiOp and the ITS. As required by Section 7 of the Endangered Species Act, the NRC conducted a biological assessment (NRC 2020) to reinitiate consultation based on SGS's recent exceedance of incidental take of sturgeon.

To identify effective measures for protecting sturgeon at the SGS cooling water intake, PSEG Nuclear LLC (PSEG) contracted Alden to perform an evaluation of technologies and operational measures (TOMs) that may have potential for reducing incidental takes of Atlantic and Shortnose Sturgeon at the Salem Generating Station (SGS) during raking of the circulating water intake trash racks. The requested evaluation of TOMs for reducing take of the two sturgeon species will allow PSEG to fully vet available approaches that may be implemented at the SGS intake to assist with mitigation of this issue. The evaluation of TOMs, as presented in this report, is based on a stepwise feasibility assessment and screening that began with a review of SGS-specific information and studies and a wide range of available technologies and measures identified for the protection of fish at water intakes. The initial review of technologies was followed by preliminary and secondary screenings guided by criteria developed specifically for the application of TOMs at the SGS intake. A detailed screening was conducted for five alternatives selected from the secondary screening as having the greatest potential for effective application, and for which general recommendations were developed for implementing multiple alternatives using an iterative and adaptive management approach.

2.0 Literature and Available Information Review

The review of literature and available information focused on sturgeon behavior that may lead to or prevent interactions with the SGS intake, as well as the design and evaluation of fish protection and exclusion measures developed to keep sturgeon out of and away from water intakes. The behavioral information is important for assessing the potential biological effectiveness of TOMs considered for application at SGS because it will provide an understanding of spatial and temporal aspects of sturgeon interactions with water intakes and subsequent behaviors and site conditions that may lead to impingement or entrainment (or to avoidance of an intake). Information and data on the evaluation and application of protective measures was reviewed to determine if any of these measures could be considered for application at the SGS intake to reduce or eliminate sturgeon take. The behavior and technology information acquired and reviewed also contributed to the assessment of likely or potential sturgeon responses to physical, behavioral, and/or hydraulic stimuli associated with various TOMs considered for reducing incidental takes and the conditions currently occurring at the SGS intake. Additionally, the literature review examined studies that have attempted to influence sturgeon behavior to prevent exposure to other manmade activities, such as dredging, pile driving, and blasting activities.

Relevant publications were identified and acquired using internet searches for peer-reviewed and gray literature. Alden's extensive library, which includes publications describing habitat use, seasonal movements, swimming capabilities, and general behaviors of various sturgeon species in North America and other locations throughout the world, was also searched for information relevant to the application of TOMs at SGS. Although a focus was placed on studies conducted with Shortnose and Atlantic sturgeons, information on other sturgeon species was reviewed and summarized given that there are often similarities in morphology and behavior among species of the same family, particularly with respect to responses to various behavioral cues, hydraulic conditions, and physical structures typically associated with water intakes and fish protection and exclusion measures.

2.1 Sturgeon Distribution and Habitat Use in the Delaware River Estuary

Historically, a large spawning population of Atlantic Sturgeon utilized the Delaware River Estuary. Overfishing and habitat loss have caused a vast decline in the population (Secor and Waldman 1999). Movement and distribution of sturgeon in the Delaware River has been poorly understood, but recent studies have begun to provide more knowledge about this species and its distribution in the Delaware River Estuary.

Distribution of Atlantic Sturgeon appears to vary by both season and age class. Adults will migrate into the Delaware River Estuary in April through July to spawn and can travel as far as Roebling, New Jersey, at rkm 201 (Breece et al. 2013). Spawning most likely occurs between rkm 136 and 211 in the Delaware River based on telemetry and habitat availability (Simpson 2008). Young-of-the-year sturgeon will remain in the river over the winter and by age 2 to 3 they will begin to migrate offshore for the winter, returning to the estuary and river in the spring and summer (Dovel and Berggren 1983).

Atlantic and Shortnose sturgeon distribution has been studied using gillnets, trammel nets, and acoustic tracking in the Delaware River estuary. Juvenile sturgeon were found to occur in the tidal-freshwater regions of the river in the spring and summer and then would move downstream to deeper water in the lower tidal river in the fall and winter (Brundage and O'Herron 2009). Similar movement of juvenile Atlantic Sturgeon was reported by Brundage and Meadows (1982), with juveniles moving upstream in the late spring and summer. Sturgeon were found in the lower tidal river from February through September with the peak being in July.

Hale et al. (2016) tagged and monitored movements of young-of-the-year and age 1 Atlantic Sturgeon in the Delaware River. Tagged fish were found to be throughout the river system from rkm 99-152, with the majority of the juveniles found between rkm 127-129 (near Marcus Hook). This area of the river seems to be an important habitat that is utilized by multiple age classes such as spawning adults and a nursery habitat for young-of-the year.

The Salem Generating Station is located around rkm 83, which falls into the formally designated critical habitat for sturgeon in the Delaware River, but is down river from the majority of critical habitats for spawning for both Atlantic and Shortnose Sturgeon (NMFS 2014, NMFS 2017, NRC 2020). However, sturgeon utilize the entire estuary and river while migrating and foraging. Juveniles, as mentioned above will migrate downstream to the lower portions of the river in the fall and winter while searching for deeper water. This would place them near the Salem intake during that time, which correlates with the time of year sturgeon have been prominent at the intakes.

2.2 Sturgeon Behavior at Water Intakes

Information on the behavior of sturgeon when they encounter water intakes is limited. Several laboratory studies have investigated entrainment and/or bypass use of juveniles, but observed behaviors in test flumes may not be representative of wild fish in the field. Additionally, most laboratory studies have been conducted with underyearling or yearling fish, which are not often encountered at the SGS intake.

Reading (1982) evaluated impingement and entrainment of White Sturgeon larvae and juveniles (17 to 63 mm in length) with varying screen opening sizes (4.0 mm diameter perf plate and 2.4 mm wedgewire) and approach velocities (0.2, 0.4, and 0.6 ft/s). Impingement occurred for 20% of sturgeon at an approach velocity of 0.2 ft/s and total impingement occurred within 5 minutes at a velocity 0.6 ft/s. Another study found approach velocities ranging from 0.6 to 1.2 ft/s resulted in 16.8% of juvenile Green Sturgeon (average 28 cm FL) and 1.6% of White Sturgeon (average 27 cm FL) being impinged (Poletto et al. 2014a). Overall, fish were found to make more contacts with the screen during the day than the night. However this differed slightly between species as White Sturgeon were found to have more contacts during the night. Green Sturgeon were found to spend 34.8% of the experimental period near the screens compared to only 18.7% by White Sturgeon.

Evaluations of bar racks and louvers have provided some behavioral information for several sturgeon species, including Shortnose, Lake, White, and Pallid Sturgeon (EPRI 2000; Kynard and Horgan 2001; Amaral et al. 2002; Kynard et al. 2005, 2006; Alden 2009, 2010). Most of these studies have been conducted in laboratory flumes, with one evaluation conducted at a field site. The flume studies indicate juvenile and sub-adult sturgeon will typically stay near the bottom and exhibit positive rheotaxis as they move downstream towards a bar rack angled or perpendicular to the flow at channel velocities of about 1 to 3 ft/s. When encountering these structures some sturgeon will rise in the water column, but generally will remain in the lower half of the water column. Radio telemetry tracking of juvenile Shortnose Sturgeon approaching and interacting with the angled louver array in the Holyoke canal also provided evidence of fish moving up and down in the water column as they moved downstream along the structure. Observations from these studies indicate that most sturgeon likely approach water intakes near the bottom, but may begin to search or explore vertically when they encounter bar racks or other types of intake screening.

In addition to behavior, which would primarily be influenced by hydraulic cues as fish approach an intake, sturgeon swimming capability is another important aspect of avoiding entrainment and impingement at water intakes. The swimming capabilities of sturgeon have been evaluated for multiple species and life stages. Maximum sustained and critical swim speed estimates range from 2.1 to 18 cm/s (0.07 to 0.60 ft/s) for larvae and 15 to 172 cm/s (0.5 to 5.6 ft/s) for juveniles, with increasing speeds for larger sub-adults and adults (Table 2-1). Although not evaluated, Atlantic Sturgeon would be expected to have similar swimming speeds as those reported for other species.

2.3 Behavioral Deterrent Technologies

Behavioral deterrents, including sound, air bubble curtains, electric fields, and various types of light, have been evaluated for their ability to repel fish and, in some instances, these technologies have been installed to reduce entrainment and impingement of fish at water intakes. Attraction has also been investigated for some stimuli (mainly continuous light sources). However, the effectiveness of behavioral deterrents (or attractants) has varied considerably among species and applications with very few of the stimuli evaluated producing consistent responses that would warrant consideration of permanent installations or wide-scale use. Testing of behavioral deterrents with sturgeon species has been limited, but there have been some studies that have investigated responses of sturgeon to artificial light and sound stimuli.

2.3.1 Light Technologies

Recent investigations of sturgeon responses to light have focused on LED illumination used as an attractant or deterrent, depending on light color. During both day and night testing, age-0 White Sturgeon (*Acipenser transmontanus*) were exposed to LED-based light guiding devices (LGDs). These tests exposed fish to green, red, or blue wavelengths at three different flashing frequencies (1 Hz, 20 Hz, or constant) in a y-maze. Test fish were significantly influenced by light color and illumination frequency. Green lights produced the most approaches (i.e., attraction) regardless of frequency during the day and night, whereas red light at 1 Hz elicited the least number of approaches (deterrence) during the day and blue light at 1 Hz had the lowest approaches during the night (Ford et al. 2018). Continuing with this research, Ford et al. (2017) tested White Sturgeon (age-0) bypass guidance efficiency in a laboratory raceway during the day and night. Using a reverse configured 45° angled louver array (meaning the slat angle is reverse to the flow), three different slat spacings (5, 10, 20 cm) were tested in combination with an LGD with green strobe light operating at 20 Hz or with a red strobe light operated at 1Hz. The red light was used as a deterrent to prevent fish from passing through the louver, whereas the green light was used to attract fish towards a bypass. The red strobe light tests produced 57 to 83% bypass efficiency with 10 and 20 cm slat spacings. Bypass efficiency was highest (97 to 100%) with louver spacings of 10 and 20 cm and green strobe light when compared to the control (no LGD or louver) at 46% (Ford et al. 2017).

Elvidge et al. (2019) tested the avoidance behaviors of age 1+ and 4+ Lake Sturgeon (*A. fulvescens*) with four different LED lights (green, blue, orange, and white) and three flashing conditions (1 Hz, 10 Hz, and constant). Age 4+ fish demonstrated the greatest avoidance to white light at 1 Hz, but also avoided blue light strobing at 1 Hz. Age 1+ fish did not demonstrate any significant avoidance to any of the light stimuli.

Poletto et al. (2014b) evaluated entrainment of juvenile Green Surgeon (*A. medirostris*) through a diversion pipe in a laboratory flume with four LED strobe light exposures (emitting 4 rapid pulses over 0.5 seconds). There was no significant difference for the number of times fish passed the diversion pipe between the strobe light condition and the control. The number of sturgeon entrained was the greatest during strobe light exposure, but there was no statistical difference from entrainment during a control.

Table 2-1. Swimming Capabilities of Sturgeon Species.

Species	Scientific Name	Life Stage	Length (mm)	Critical Swimming Speed (cm/s)	Maximum Sustained Speed (cm/s)	Burst/ Escape Speed (cm/s)	Temperature (°C)	Source
Lake	*Acipenser fulvescens*	juvenile	230-550	--	25	--	7	Peake et al. 1995
		juvenile	230-550	--	40	--	21	Peake et al. 1995
		larvae	<150	--	4	--	14	Peake et al. 1995
		adult	>1000	--	90	--	14	Peake et al. 1995
Pallid	*Scaphirhynchus albus*	juvenile	--	37	--	--	20	Adams et al. 2003
		juvenile	--	15	--	--	10	Adams et al. 2003
		juvenile	170-205	--	25	55-70	17-20	Adams et al. 1999
		juvenile	130-168	--	10	40-70	17-20	Adams et al. 1999
Shortnose	*Acipenser brevirostrum*	larvae	70	--	18	--	--	Deslauriers and Kieffer 2012
		larvae/juvenile	66-211	2 - 45	--	--	15	Katapodis and Gervaise 2016
Shovelnose	*Scaphirhynchus platorynchus*	juvenile	--	37	--	--	20	Adams et al. 2003
		juvenile	494-705	89 - 172	--	--	20-25	Hoover et al. 2011
		juvenile	--	19	--	--	10	Adams et al. 2003
White	*Acipenser transmontanus*	larvae	<82	--	--	38	18-24	Boysen and Hoover 2009
		larvae	82-92	--	--	42	18-24	Boysen and Hoover 2009
		larvae	>93	--	--	45	18-24	Boysen and Hoover 2009
		juvenile	342	56	--	--	12	Katapodis and Gervaise 2016

Light levels that are not naturally occurring, such as strobe lights, have been found as an effective deterrent for some fish. Therefore, PSEG requested laboratory studies to evaluate the effects of strobe lights as a deterrent for common species found at the Salem intake, which did not include sturgeon. Three intensity levels were tested with Alewife with promising results. When turbidity levels (< 50 NTU) were tested at Salem, the perimeter of strobe lights was thought to only be 6 ft making the installation of lights relatively ineffective (ARL 2005).

2.3.2 Sound Deterrents

Various types of sound deterrents have been investigated for their ability to effectively repel a wide range of species to reduce entrainment at water intakes. Sound deterrents are typically classified as infrasonic (less than 100 Hz), sonic (100 Hz to about 80 kHz), and ultrasonic (greater than 80 kHz). The frequency range used for fish deterrence is dependent on the hearing capability of target species. For example, ultrasonic sound signals have been shown to be a very effective deterrent for clupeid species of the genus *Alosa* [e.g., American Shad (*Alosa sapidissima*), Alewife (*Alosa pseudoharengus*), Blueback Herring(*Alosa aestivalis*)] (Popper 2003). Alosids are the only species that have been shown to have the ability to hear ultrasonic sounds. Fish classified as hearing specialists typically can detect sound frequencies up to about 5 kHz, whereas non-specialists can only hear frequencies less than 1,500 Hz.

In 1994, a series of cage test were conducted at Salem to identify specific sound signals that had potential to deter fish from the CWIS (Cooling Water Intake Structure). *Alosa* species demonstrated strong avoidance to ultrasonic signals whereas other representative important species at Salem exhibited only weak avoidance to low-frequency (sonic) signals. In 1998, additional cage sound deterrence testing was conducted at the Salem Generation Station CWIS based on the results from the 1994 tests. An ITC-3640 wide-beam transducer producing 162 dB of high frequency sound and a G34 transducer that produced low frequency sound were installed at two of the intake bays (Unit 1 and 2). However, results indicated that there was very limited difference in responses. Reductions in impingement were seen for Bay Anchovy (*Anchoa mitchilli*), Atlantic Silversides (*Menidia menidia*), and Atlantic Croaker (*Micropognias undulatus*) (PSEG 1999). In 2001 through 2004, sounds studies were repeated in the lab and in the vicinity of the Salem CWIS. Sonic (100-400 Hz sweep, 500-3,000 Hz sweep) and ultrasonic transducers (80-120 kHz) were tested in the field and found avoidance in many of the clupeid species as well as Bay Anchovy and Atlantic Silversides. Significant deterrence was not seen for species of the Moronidae or Scianidae families (ARL 2005). However, no sturgeon were collected throughout these studies.

Sturgeons are considered hearing non-specialists with no specialized anatomical features to enhance hearing capabilities. They only have one chamber in the inner ear that contains small calcium carbonate crystals compared to three chambers which each have single dense calcareous otoliths seen in most teleost fish (Popper 2005). To date, there has been only one laboratory study that investigated the use of sound to repel sturgeon (Dennis 2019), which found no discernable responses of Lake Sturgeon (*Acipenser fulvescens*) exposed to high frequencies sounds (1 to 10 kHz) simulated by outboard motors.

The effects of man-driven sounds on aquatic organisms have been researched thoroughly. Exposure to pile driving can cause severe injuries including hematomas and deflating the swim bladder when exposed to high sound levels for an extended period of time (Halvorsen et al. 2012). While injuries can occur with high exposure, sturgeon have been known to avoid areas with pile driving. Atlantic Sturgeon were found significantly less in areas with pile driving than compared to controls (no pile driving) and the fish that did remain in those areas were only there for a short time (Krebs et al. 2016). Based on this research with sturgeon and pile driving, boomers have been used operationally by the US Army Corp of

Engineers and approved by NMFS to deter sturgeon from blasting and dredging sites. In 2015, the US Army Corp multiple methods to protect sturgeon from blasting as part of the channel deepening project for the Delaware River. These methods included relocation trawling to move sturgeon 40 miles upstream, sonar for presence observations, and the use of boomers for an acoustic deterrent (NMFS 2018). The boomer was a electromagnetically driven sound which produced 204 dB re 1uPa peak at 20/min with peak noise not to exceed 193 dB (mimic pile driving) continuously for 5 hours prior to blasting (NMFS 2018). Prior to the blasting, an experimental study was conducted to test the feasibility of loud impulsive underwater sound (i.e. boomers) in the Delaware River in March-May of 2015. Atlantic and Shortnose Sturgeon were found to spend 4.55 hours less in the area when the sounds was "on" compared to "off", which was approximately 50% less time (ERC 2015). Unfortunately, these results were not significant due to the low sample size.

2.3.3 Electric Barrier and Guidance Technologies

Electric fields have been evaluated and installed to block or guide fish moving upstream and downstream, as well as from entrainment at cooling water intakes. However, the dissipation of electrical energy in water can affect the ability of electric fields to deter fish as it may vary from taxis to immobilization depending on distance from the electrical source, fish size and species, and water conductivity. Chondrostean fish (e.g., sturgeons and paddlefishes) possess arrays of electroreceptors (ampullae of Lorenzini) on the snout and gill covers that allow these species to detect small electric field gradients. Bouyoucos et al. (2013) conducted a laboratory study assessing juvenile Atlantic Sturgeon interactions with a weak electric field that was produced by an electropositive (EP) metal. Although the electrical field affected sturgeon behavior, avoidance only occurred in the presence of food. Stoot et al. (2018) assessed the effects of low-frequency, low-voltage electric fields as a deterrent for juvenile Lake Sturgeon. Behavioral responses varied among individuals and age classes, and some fish showed signs of acclimatization over time even with increasing voltages.

2.3.4 Air Bubble Curtains

Air bubble curtains have been tested for the ability to deter fish during laboratory and field studies. For these devices, air typically is pumped through a diffuser to create a constant stream of dense bubbles. Bubble curtains are thought to produce visual and sound stimuli that act to repel or deter passage through the bubble field. Low-frequency sound is generated by bubbles detaching from the diffuser. In addition, rising bubble plumes generate turbulence and may also serve as a visual barrier by obscuring a fish's line of sight (Zielinski et al. 2014). Over the years, there have been multiple studies with installations of air bubble curtains in an attempt to prevent fish from entering CWIS. Although results have not been promising for the majority of fish species, positive deterrence results have been shown for multiple carp species. In some instances, sound transducers and strobe light have been combined with air curtains to create multiple aversive stimuli to increase fish repulsion. The performance of these hybrid systems has varied considerably, with few effective installations.

2.3.5 Water Jets and Turbulent Flow Fields

Turbulent flow fields have been investigated as a guidance technique for directing fish away from water intakes and towards fish bypasses. Turbulent flow stimuli or cues can be active or passive. Active induction is achieved by the use of technologies such as submerged waterjets or propellers, whereas passive induction uses ambient velocities to generate turbulence by placing structures (e.g., submerged vanes and berms, pilings, concrete cylinders) in strategic locations (Coutant 2001). There have been few rigorous evaluations of turbulent flow fields for guiding fish away from water intakes and available data have not indicated high levels of effectiveness. Most studies of these technologies have been conducted with salmon smolts, with limited testing on silver American (*Anguilla rostrata*) and European (*Anguilla anguilla*) eels as well.

2.3.6 Carbon Dioxide

Carbon Dioxide (CO2) has become a promising new deterrent due to the fact that it is naturally occurring and soluble as well as it is commercially available. Exposure to elevated CO2 can reduce fishes blood pH and decrease O2 transport efficiency (Gelwicks et al. 1998; Treanor et al. 2017). Once fish are exposed to CO2, fish can experience erratic swimming, impaired sensory systems, loss of equilibrium, or even mortality in high doses (Kates et al. 2012; Munday et al. 2009; Ross et al. 2001; Treanor et al. 2017). Studies in the lab and field have mostly focused on invasive carp species, with positive results. Only one study to date has included a similar species to surgeon, Paddlefish (*Polyodon spathula*). However, no significant response was found when CO2 (30.3-59.0 mg/L) was released using manifolds into a pond (Donaldson et al. 2016).

2.4 Physical Exclusion Technologies

Physical exclusion and guidance structures, such as barrier nets, bar racks, and louvers, have been used to reduce or eliminate fish entrainment at a variety of water intakes. Some of these devices have been successful at excluding or guiding sturgeon depending on design parameters and site configuration and hydraulic conditions. High guidance efficiencies (85 to 100%) have been demonstrated for several sturgeon species (Shortnose, Lake, and Pallid) tested with angled bar racks and louvers in laboratory flumes (EPRI 2000; Kynard and Horgan 2001; Amaral et al. 2002). Similar efficiencies were estimated for Shortnose Sturgeon evaluated for guidance along a louver array installed in the Holyoke Canal on the Connecticut River (EPRI 2006a).

The flume studies conducted by Amaral et al. (2002) demonstrated that guidance of Shortnose and Lake Sturgeon along an angled bar rack and louver array was improved when a solid panel was installed on the lower 12 inches of the structure. This design reduced entrainment and increased guidance of sturgeon that were in close contact with the flume floor. Because sturgeon are generally benthic, blocking the lower portions of intakes with solid panels or walls may provide greater protection from entrainment at some water intakes.

2.5 Operational and Hydraulic Modifications

Other than ceasing water withdrawal operations, the implementation of modifications to intake operations or hydraulic conditions (e.g., reduced approach velocities) has not been investigated as potential approaches to reducing entrainment of sturgeon. However, a maximum intake velocity of about 2 ft/s has been shown to reduce impingement and entrainment of juvenile and sub-adult sturgeons approaching a bar rack oriented perpendicular to the flow during laboratory studies when compared to velocities as high as about 3 ft/s (Kynard et al. 2005, 2006; Alden 2009, 2010).

3.0 Review of Sturgeon Occurrence and Behavior at the SGS Intake

The study methods and findings of sturgeon sonar surveys conducted in the vicinity of the SGS and at the intake during the spring of 2020 (Hudson Engineering and ERC 2020) and the incidental take records from the trash rack were reviewed to identify information and observations that could assist with the assessment of TOMs and development of an effective approach for reducing sturgeon take. In addition to temporal and spatial data for fish in the vicinity of the intake, the data collected from the surveys and pilot testing of sonar devices on the trash rake and intake structure provide behavioral observations of sturgeon interacting with the trash racks. For the evaluation of TOMs, it is important to have an understanding of direction and depth of movement at the intake throughout the tidal cycle and whether sturgeon presence is influenced by tidal stage. In addition to assessing the information gathered from these surveys and the incidental take records and using it for the assessment of TOMs, recommendations are provided for future similar studies that may provide more specific and robust data that can be used to optimize the design and operation of protective measures.

3.1 Sonar Study Approach

The sonar surveys, as reported by Hudson Engineering and ERC (2020), included an in-plant trash bar assessment and an in-river sidescan sonar study. The study report provides detailed information on the selection of sonar technologies and their design, operation, and use. A Soundmetrics ARIS Explorer 3000 acoustic camera and a Hummingbird 900C HD were selected for the trash bar assessment and Marine Sonic HDS dual frequency (600/1200 kHz) sidescan sonar was selected for the in-river study. However, the Hummingbird transducer was damaged during its initial deployment. Consequently, the ARIS provided the only useful observations for the assessment of the intake bar rack. Acoustic images were collected with the ARIS at Unit 2 intake bays 22A and 21B and Unit 1 intake bays 13A and 13B. Unit 2 was not in operation during the ARIS survey whereas Unit 1 was.

3.2 Sonar Study Findings

Several fish were observed at the trash racks during the Unit 1 survey. Acoustic images also showed significant debris accumulation, most of which was located on the lower portion of the trash racks with less towards the surface where raking was more effective. Fish were observed swimming in the vicinity of the trash rack, some of which were considered to potentially be sturgeon. Most fish activity was observed off the bottom and adjacent to the trash racks and there were no observations or evidence of impingement. Flow movement was also observable based on air bubble and debris movement. The assessment of Unit 1 was conducted during trash rake operations. Logistical constraints associated with the deployment of the ARIS and movement of the trash rake prevented coverage of areas below the rake. During the Unit 1 assessment, two Atlantic Sturgeon were collected by the rake.

The in-river sidescan sonar surveys were conducted adjacent to the entire Artificial Island complex with a focus on the area in front of the SGS intake. Forty-one (41) possible sturgeon targets were located during these surveys. The estimated length range of the targets was 52 to 158 cm with an average of 74.0 cm. The probability of fish targets being sturgeon was qualitatively ranked from low to high. Targets considered to potentially be sturgeon were scattered throughout the study area and no dense aggregations were observed. One sturgeon target was located within a meter of the SGS circulating water intake and two were within about 2 m of the service water intake. Based on these conditions, the report authors concluded that there were not any conditions that might explain the high incidence of take that had occurred in recent months.

3.3 Incidental Take Records at SGS Trash Rack

Over the last seven years, 103 Atlantic Sturgeon have been collected from the trash rack. The highest numbers have been in the last two years with a total of 22 sturgeon in 2019 and 49 in 2020 (Figure 3-1). The majority of the sturgeon were collected in December, March and April. Fork lengths of sturgeon ranged from 44 -116.7cm. The majority of sturgeon collected were within 60-80 cm and had an overall average length of 83.6 cm (Table 3-1).

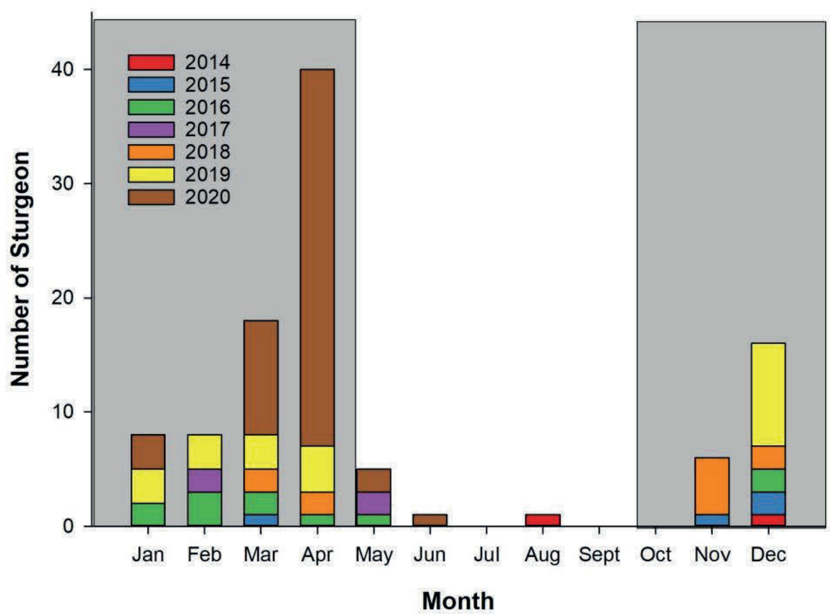

Figure 3-1. Atlantic Sturgeon counts by year and month from the SGS trash racks. Shaded areas indicate when the ice barrier is currently installed.

Table 3-1. Length frequency of Atlantic Sturgeon by month at the SGS trash rack.

	Month												All
Length Bin (cm)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Months**
40-50	2	0	0	0	0	0	0	0	0	0	1	0	3
51-60	2	2	1	9	0	0	0	0	0	0	0	5	19
61-70	2	2	9	10	2	1	0	0	0	0	2	6	34
71-80	0	0	3	16	0	0	0	0	0	0	2	2	23
81-90	0	1	1	3	1	0	0	0	0	0	1	1	8
91-100	0	1	0	0	0	0	0	0	0	0	0	0	1
101-200	1	0	0	0	1	0	0	0	0	0	0	0	2
200+	0	1	1	1	0	0	0	0	0	0	0	1	4
Unmeasurable	1	1	2	1	1	0	0	0	0	0	0	1	7
Total Count	8	8	17	40	5	1	0	0	0	0	6	16	101
Average FL (cm)	62	91	116	72	82	60	-	-	-	-	67	99	83

3.4 Implications for Selection of TOMs to Reduce Take

The trash rack sonar assessment and in-river surveys demonstrated that the equipment and techniques used were sufficient to identify sturgeon targets. The images and data collected indicated sturgeon were present at the intake and in the river areas around Artificial Island during the study period. The presence of sturgeon in the vicinity of SGS is not unexpected given what is currently known about Atlantic and Shortnose Sturgeon movements in the Delaware River. The riverine estuary habitat surrounding the SGS location likely provides water quality, physical characteristics, and food types and abundances sought by these species. Sturgeon that encounter the SGS circulating water intake are likely foraging and could be actively seeking food on and around the trash racks throughout the water column. This would explain the take of sturgeon by the trash rake at locations higher in the water column. However, vertical movements by sturgeons have been observed at other types of water intakes (e.g., hydropower facilities with bar racks or guidance structures) and may be a response to following flow direction and the need to find a passage route.

Impingement of sturgeon on the SGS intake trash racks was not observed and is not expected to occur because fish that are too large to pass through the bar opening (3 inches clear) have sufficient swimming abilities to overcome the intake approach velocities (less than 2 ft/s). Therefore, incidental take of sturgeon has resulted from capture in the trash rake. Consequently, for the assessment of potential TOMs to reduce or eliminate sturgeon take, it will be important to determine the most effective methods to keep sturgeon from encountering the rake and being trapped in it during raking operations.

The sonar data indicate that at any distance away from the intake, sturgeon are likely near the river bottom, but will rise or make forays higher in the water column when at the intake. Therefore, protection measures may need to cover the entire water column at the intake unless sturgeon can be intercepted and diverted away as they approach on the river bottom.

4.0 Review of Previous Fish Protection and Debris Handling Information for the SGS CWIS

This task focused on the review of all prior documents in the public record relating to impingement and entrainment reduction technologies investigated for application at the SGS CWIS. This includes previously conducted evaluations of alternative entrainment reduction TOMs that were submitted to the NJDEP as part of NJPDES Permit Renewal Applications in 1999 and 2006; and PSEG's submittals for the 2014 Rule. The review of this information ensures that any TOM considered for the reduction of incidental take of sturgeon will not negatively affect or interfere with impingement mortality compliance or the entrainment reduction TOMs identified in the Comprehensive Technical Feasibility and Cost Evaluation Studies and Benefits Valuation Studies.

Another important issue associated with the application of sturgeon TOMs at SGS is seasonally high debris loading that has historically produced operational issues and concerns at the intake. Debris loading issues were reviewed to ensure that any TOM recommended to address incidental take of sturgeons will not negatively affect or hinder debris removal and handling at the intake.

4.1 Site Description

Salem is a two unit nuclear generating facility, located on the east shore of the Delaware Bay, approximately 50 miles upstream from the mouth of the bay on the southern end of a peninsula known as Artificial Island (Figure 4-1). Salem draws water from the Delaware River Estuary through two intake structures, a service water intake and a circulating water intake. The circulating water intake is a shoreline cooling water intake structure (CWIS) for use in a once through cooling water system. After passing through the station, warmed circulating water is discharged offshore. The primary components of the circulating water system (CWS) include the circulating water intake structure, pumps, condensers, and the discharge.

The CWIS is comprised of 12, 11 ft-2 in. wide intake bays (Figure 4-2), each equipped with an ice barrier, a trash rack, a traveling water screen, and a circulating water pump. In the winter months, a removable ice barrier consisting of wood bars with structural steel braces is installed in front of the intakes. The barriers are installed in late fall (October) and remain through the early spring (May) to prevent damage to the intake pumps during heavy ice conditions. The ice barrier is installed and removed with the use of a crane, reaching over the intake bays for access. The bottom of the ice/debris barrier is at El. 78.9 ft Public Service Datum (PSD), 28.9 ft above the invert of the CWIS (El. 50.0 ft PSD). The ice barrier is installed to prevent large sheets of ice from entering the CWIS. If the sheet ice enters the trash rack, it can become problematic, accumulating against the trash rack eventually plugging it. The barrier is made out of wooden timbers and contains openings approximately 3 inches wide, slightly larger than the trash rack. When clean of debris and ice, these openings allow for flow to pass through.

Each intake bay (Figure 4-3) has a trash rack located downstream of the ice barrier. The steel trash racks extend over the full depth of the intake and are sloped at about 1.0 ft horizontal to 6.4 ft vertical. The trash racks are 0.5 inch wide vertical bars with 3.5 inch bar spacing on center, resulting in 3 inch clear openings between bars. As required by the incidental take statement (ITS), the trash racks are cleaned at least once per week year-round. Each bay has an intake isolation gate guide located approximately 4 ft downstream of the trash racks at the operating deck. The vertical traveling water screens are located about 13 ft downstream of the isolation gate guide (about 17 ft downstream of the trash racks at the deck level). These traveling water screens represent the state of the art in fish-friendly traveling water screens. The circulating water pumps are located 30 ft downstream of the traveling water screens.

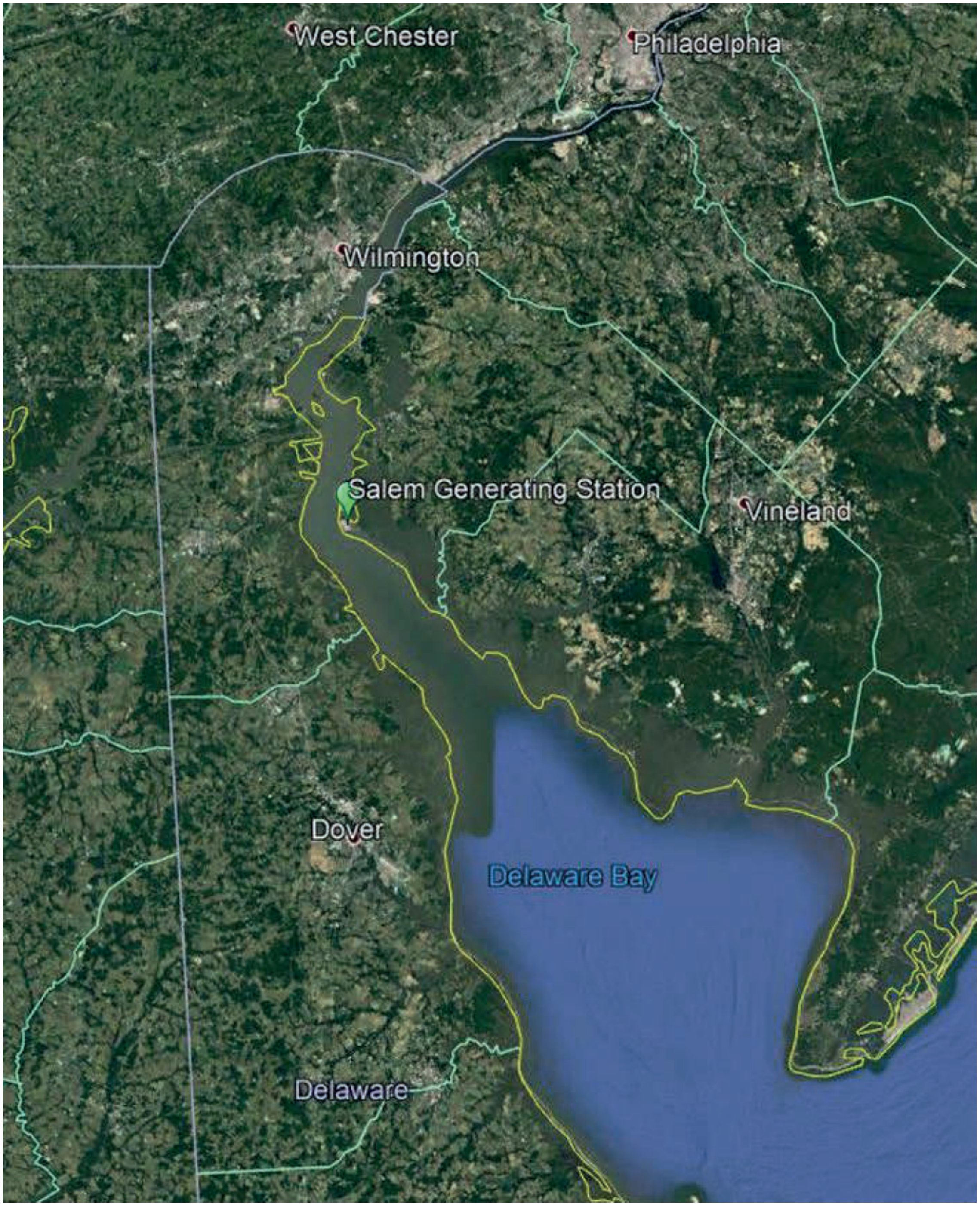

Figure 4-1. SGS location map.

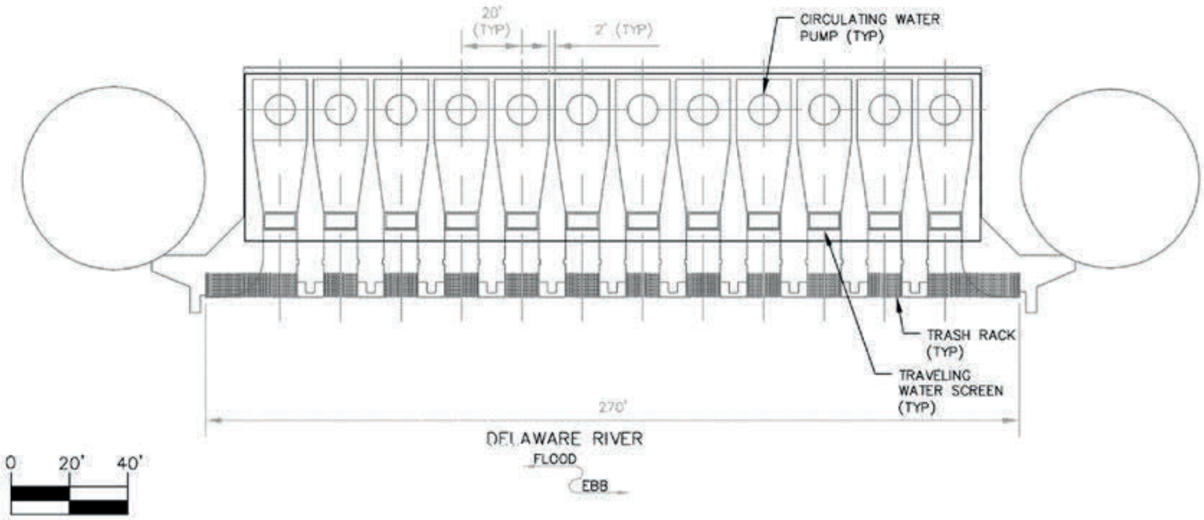

Figure 4-2. SGS intake plan.

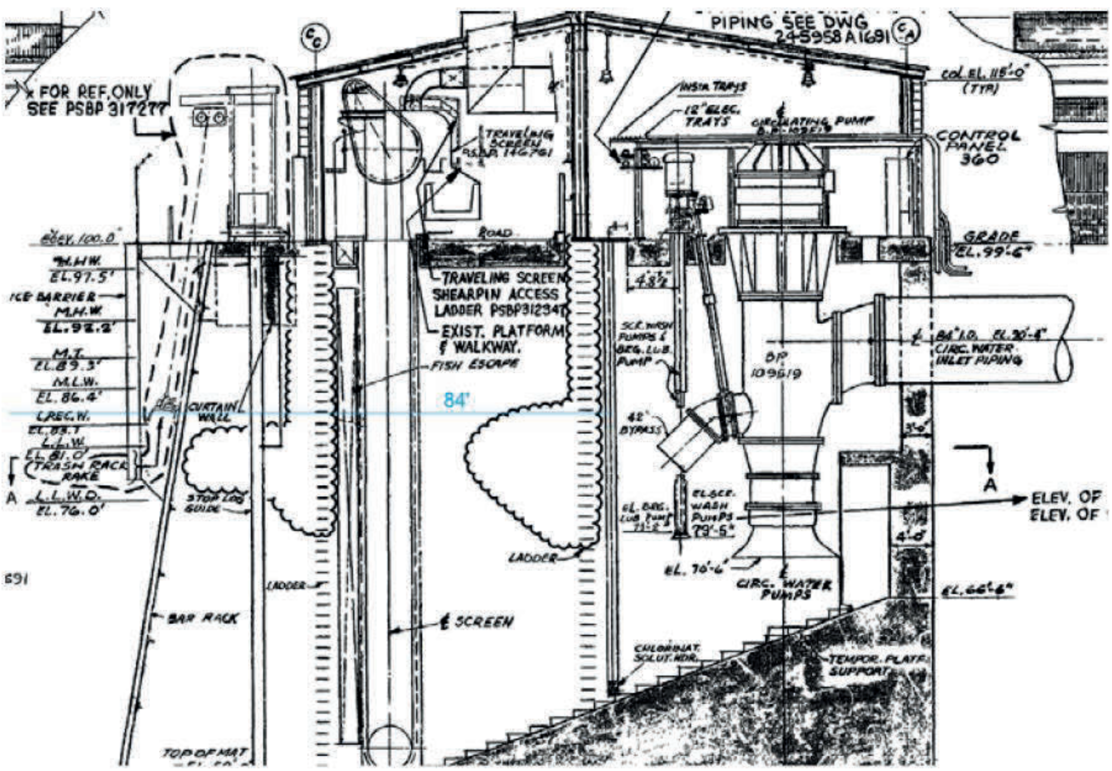

Figure 4-3. SGS intake section.

The CWIS is designed to operate at river levels ranging between El. 81.0 ft and El. 100.5 ft PSD. PSD is an arbitrarily assigned scale where Station grade is set at El. 100.0 ft PSD which correlates to El. 11.0 ft Mean Sea Level (MSL) datum. The Delaware River is tidal at the Station with water levels fluctuating on average about 5.8 ft, from mean high tide, El. 92.2 ft PSD, to mean low tide, El. 86.4 ft PSD. Maximum river velocities in front of the CWIS are generally 1.0 to 1.5 ft/sec with ebb tide (flow downstream) and 1.5 to 2.0 ft/sec with flood tide (flow upstream) during normal summer hydrologic conditions (ARL 2004).

4.2 Permitting History

Salem has been permitted under the Clean Water Act (CWA) since its initial permit in 1975. Starting in 1994, each permit renewal application has required the evaluation of techniques and technologies to help reduce impingement and entrainment at Salem. The following section summarizes the evaluation of alternative TOMs for each permit renewal application that played a role in reducing impingement and entrainment at Salem. Salem has submitted permit renewal applications in 1993, 1999, 2006; and the current 2021 application. During each application, technology and operational measures have been explored and added to reduce any risk of entrainment or impingement at the cooling water intake structure. The permit applications required PSEG to explore impingement and entrainment technologies, management practices, and operational measures to minimize the impingement and entrainment or species.

4.3 NJPDES Permit Renewal Application 1993

After submission of the permit renewal application supplement in 1993, the final NJPDES permit was issued for the station in July of 1994. The final permit included a best technology available determination for the CWIS at Salem. The permit required certain technological upgrades, operational measures, feasibility testing, and monitoring studies as best technologies available for Salem. In response to these permit requirements, PSEG implemented TOMs at the station. These TOMs included a monthly average intake flow limitation of 3,024 million gallons per day and an upgrade of the CWIS intake screens to Modified Traveling Water Screens (MTWS). MTWS are similar to standard traveling water screens except they include fish-friendly features such as smooth mesh panels, improved fish buckets, a low-pressure fish spray and a fish-friendly return. PSEG was also required to conduct operability testing on the newly installed MTWS. Sound and light deterrents were also tested for efficacy in reducing impingement. Finally, the last required aspect of the 1994 Permit required PSEG to develop a comprehensive biological monitoring program under the guidance of the permit-required Monitoring Advisory Committee (PSEG PRA Part I).

4.4 NJPDES Permit Renewal Application 1999

After submission of a detailed permit renewal application submitted by PSEG in 1999, NJDEP issued a final permit for the station in July of 2001, becoming effective in September of 2001. To address the BTA requirements under Section 316(b), the permit required a continuation of the intake flow limitation imposed in the 1994 NJPDES Permit including continued use of the MTWS/Fish handling and return system at the CWIS, improvements to the CWIS fish handling and return system(FHRS), studies to evaluate whether improvements to the MTWS/FHRS could be made to further reduce latent impingement mortality at the CWIS, a study of a the biological efficacy of a multi-sensory hybrid system to reduce impingement, and an expanded biological monitoring program. PSEG concluded that the fish handling and return system did not add to the overall impingement mortality, requiring no more modifications. PSEG also concluded that ambient water conditions in the vicinity of the CWIS precluded the application of behavioral deterrents, showing the study as inconclusive as to whether behavioral deterrents would reduce impingement mortality (PSEG PRA Part I).

4.5 NJPDES Permit Renewal Application 2006

PSEG was required to submit a permit renewal application to NJDEP again in 2006. This permit renewal application included 5 main sections:

1. Request for Renewal of Section 316(a) Variance and its attachments (PSEG 2006a)
2. The Comprehensive Demonstration Study and its attachments (PSEG 2006b)
3. The Adverse Environmental Impact and its attachments (PSEG 2006c)
4. Assessment of Alternate Intake Technologies and its attachments (PSEG 2006d)
5. The Restoration Production Estimates and its attachments(PSEG 2006e)

At the time of the renewal application submittal, the 316(b) Phase II Rules were in effect. The 2004 Phase II rule established requirements to reduce impingement and entrainment and provided several compliance alternatives. Permittees were required to show compliance with this rule through preparation and submission of a report referred to as the Comprehensive Demonstration Study (Section 2) (USEPA 2004). TOMs and/or restoration measures were presented that would satisfy the performance standards as part of the Technology Installation and Operations Plan (TIOP). The TIOP required weekly inspections of the CWIS and MTWS, including the screen panels, fish buckets, flap seals, screen wash system, the fish handling and return system to ensure they were operating properly to achieve reductions in impingement and entrainment (AKRF Inc, 2019). It should be noted that the 2004 316(b) Phase II Rule was suspended on July 9, 2007 in part because the U.S. Court of Appeals for the Second Circuit concluded that the statute did not authorize restoration measures to comply with 316(b) requirements. With the suspension of the 2004 Phase II Rule, NJDEP did not issue a new operating plan for Salem until June of 2016 after the finalization of the CWA Section 316(b) Existing Facilities Rule.

4.6 NMFS 2014 Biological Opinion

NMFS issued a biological opinion in 2014 as part of the Endangered Species Act Section 7 Consultation with the NRC to support renewal of the Operating Licenses for Salem and Hope Creek Generating Stations. This opinion included detailed descriptions of the listed species in the area and effects of continuing operations on those species. The species of concern was comprised of Atlantic Sturgeon, Shortnose Sturgeon, Green Sea Turtles, Loggerhead, and Kemp's Ridley Sea Turtles. The focus of the biological opinion is to determine whether or not continued operation could jeopardize these species and to make recommendations to minimize or avoid any adverse effects. NMFS determined that Salem and Hope Nuclear Generating Stations may adversely affect these species through entrainment, impingement or through capture during required surveys. However, these affects will be insignificant or minimal. The two stations are not thought to jeopardize the survival of the populations of any of these species.

4.7 NJPDES Permit Renewal Application 2019 316(b) Report Part I

In July of 2019, PSEG submitted the first of three parts of SGS's permit renewal application to the New Jersey Department of Environmental Protection. This submittal included information on the best technology available determinations for the CWIS and the SWIS. PSEG has chosen to demonstrate compliance for impingement mortality under Section 125.94 compliance option (c)(6), which creates a system of technologies and operational measures, or TOMs, on a facility wide basis for both the CWIS and SWIS.

Entrainment characterization studies required as part of the 2014 Rule have been completed at SGS and are also included in the Part 1 report. These studies provide substantial data and information on entrainment survival rates and are appropriate to use for entrainment loss estimates for certain species and life stages. This permit application submittal satisfied the requirements of the 2016 NJPDES Permit which required early submittal of studies to address specific parts of the EPA Section 316 (b) Rules.

4.8 NJPDES Permit Renewal Application 2020 Section 316(b) Report Part II (Draft)

Included in the 2020 permit submission that was due on August 1, 2020 was a detailed review of TOMs for the CWIS and SWIS to reduce entrainment at Salem, which was reviewed by Alden. Fifty TOMs underwent a multiple phased screening process. After the screening process was complete, four TOMs were determined to be suitable for the CWIS. These four TOMs were selected to undergo a Comprehensive Technical Feasibility and Cost Evaluation Study. They included:

1. Closed Cycle Recirculating Water System with Natural Draft Cooling towers
2. Narrow Slot Cylindrical Wedge Wire Screens
3. Dual Flow Fine Mesh Ristroph Type Modified Traveling Water Screens
4. Flow Reductions with Variable Frequency Drives With the Existing Pumps

After completion of the screening process for the SWIS, it was determined that no TOM was suitable to undergo a Comprehensive Technical Feasibility and Cost Evaluation Study (PSEG, 2019).

4.9 NRC 2020 Biological Assessment

NRC issued an updated biological assessment as part of the Endangered Species Act Section 7 reinitiated consultation for the continued operation of Salem and Hope Creek Nuclear Generating Stations in June 2020. This assessment included a detailed description of Atlantic Sturgeon Delaware River population and their designated critical habitat, incidental take data, potential impacts to the species, and mitigation strategies. The focus of the biological assessment was to determine the impacts to Atlantic Sturgeon and its designated critical habitat. The NRC concluded that Salem will have adverse effects to Atlantic Sturgeon from impingement into the CWIS but will not affect their critical designated habitat. This evaluation is mentioned in the updated Biological Assessment and was conducted to investigate possible mitigation strategies.

4.10 Measures Implemented to Reduce Impingement and Entrainment at Salem

Within the past permit applications, many fish protection alternatives have been analyzed for implementation at Salem to reduce impingement and entrainment of fish. A characteristic of the SGS intake that has been considered important in reducing impingement at the plant is the small area of influence (AOI). The AOI extends approximately 150 ft offshore of the CWIS, which is a relatively small distance when compared to the size of the river and the strength of the tidal currents.

Along with measures to reduce impingement and entrainment, under Salem's 1994 NJPDES Permit PSEG made improvements to the MTWS at Salem's CWIS. The CWIS was determined to be the best technology application for Salem at the conclusion of these modifications (NJDEP 1994, 2001, 2016). The improvements made to the MTWS are the following:

1. Composite Material Fish Buckets

As improvements to the traveling water screens were made in 1994, the original steel buckets were replaced with newly designed hydrodynamically-improved fish buckets. The new buckets include a newly designed curved "leading edge" which reduces turbulent flow patterns and minimizes injuries to fish and shellfish. Each bucket had been designed with an interlocking seal to the frame around it, which maximizes the chance that impinged organisms will be sent to the fish handling and return system, reducing entrapment.

2. 0.50 x 0.25-inch Smooth-tex® Wire Mesh Screen Panels

As part of Salem's 1994 NJDPES Permit, the original 12-gauge stainless steel woven wire mesh was replaced with Smooth-tex® mesh. The new wire is 14 gauge instead of 12 gauge, resulting in less wire obstruction in each screen panel and providing an approximate 25% increase in the openings and a 20% reduction in the through-screen velocity; this reduction in velocity decreases the force a fish experiences if it is impinged on the screen.

3. Enhancements to Spray Wash Nozzle Configuration

The spray wash water system was modified to improve flow to the MTWS system. Eight spray nozzles were added to the spray headers of each MTWS. Two low pressure spray nozzles were added to each end of the source pipe at the end of the two fish spray headers (a total of four nozzles) to improve the fish handling from the screens to the buckets. The low pressure spray nozzles operate at 15 psi, a selected pressure to minimize descaling of fish.

Two high pressure spray nozzles were added to each of the two debris spray headers to help improve debris removal in the system. These high pressure spray nozzles operate at 90 to 100 psi and configured to avoid directly spraying fish. To test whether the spray wash system was effective, PSEG conducted a laboratory study using a fully functioning pilot-scale system. Minimum impingement mortality was observed up to the maximum pressure of the debris removal system (100 psi).

4. Fish Return Trough

The Salem traveling water screens were originally equipped with a rectangular front trough for both debris and fish. This trough has been replaced with a separate rear debris and fish troughs. The fish trough is 30 in wide and 18 in deep and made of smooth fiberglass with rounded corners and bottoms which are minimally abrasive to fish. This trough sits parallel and above the separate debris trough and discharges back into the estuary.

5. Improved Flap Seals

Neoprene flap seals were redesigned and used to replace the existing seals between the traveling water screen frames and the fish debris troughs. The newly designed seals were redesigned to create a tighter seal along the MTWS, therefore reducing the chance of fish or debris traveling to undesired locations and eliminating the risk of entrapment.

6. Continuous Screen Rotation

The MTS at Salem can operate at variable speeds between 6 and 35 fpm. The screens are fully automated so that the screen rotation speed increases as the differential pressure across the screen increases. By increasing rotation speed on the screens during periods of high debris loading, less debris has accumulated on the screens allowing for the spray wash system to be more effective at removing impinged fish from the screens.

7. Management Practices That Ensure the Continued Effectiveness of the MTWS and Fish handling and return system.

In accordance to the 2001 NJPDES Permit, PSEG is required to conduct a system of inspections as well as conduct preventative maintenance measures to ensure the continued efficiency of the MTWS and fish handling and return system. Also, PSEG has implemented a protocol for addressing potential problems with the CWIS. This system allows users to input problems observed which then assign work orders as well as automatically generating periodic maintenance activities to individuals or organizations. All work orders are then tracked until completion (PSEG PRA Part I).

4.11 Debris Handling

In addition to relatively high prevailing water velocities near the Station, which prevents suspended matter from settling, Salem is located in the transition zone of the Estuary. The transition zone has high turbidity, variable salinity, and low biological productivity. Turbidity levels and suspended solids peak in this zone as a function of relatively strong tidal currents and re-suspension of fine grain sediments. The transition zone is also an area where colloidal particles aggregate due to the mixing of fresh and brackish waters. In addition to the finer suspended materials, larger organic detritus, much of it originating in the marshes along the margin of the bay, accumulates in the Delaware River near the Station. As a result, this segment of the Estuary typically has, by far, higher concentrations of suspended solids than any other location in the main stem Delaware system (ARL, 2004).

Under current state, Salem utilizes a traditional Brackett Bosker trash rake, which slides down the rack and grabs debris that is stuck along the face of the rack. Due to the high debris loading seen at Salem, PSEG indicated the racks need to be cleaned frequently, on top of the once a week requirement. Once over a foot of head loss is seen through the rack, PSEG initiates the cleaning process, using the rake to clean debris from all bays. This process is continued until the head loss is minimized and all debris which can be removed by the rake is removed. However, it was indicated that portions of the rack have biofouling and become difficult to clean with the Bracket Bosker rake.

5.0 Evaluation Tools

This section presents the criteria used to evaluate technologies and operational measures (TOMs) that may have potential for reducing incidental take of Atlantic and Shortnose Sturgeon at SGS. These take events occur during raking of the circulating water intake trash racks. As such, the TOMs and associated evaluation will focus on a method to keep sturgeon from interacting with the trash rack and rake. The evaluation of TOMs, as described in the following sections, relied primarily on available scientific literature (gray and peer-reviewed publications) and professional judgement supplemented by some simple engineering calculations of hydraulic conditions at the intake.

5.1 Evaluation Criteria

The TOMs will be evaluated for their potential for successful application at the SGS intake based on the following criteria:

- Development Status
- Performance Certainty
- Nuclear Safety
- Design Complexity
- Construction Complexity
- Permitting
- Flexibility and Adaptability
- Reliability and Redundancy
- Operation and Maintenance Complexity
- Impact on Existing CWIS Operations (with respect to debris handling and fish protection)
- Life-Cycle Cost

The factors considered in scoring and eventual ranking of the alternatives are presented below.

5.1.1 Development Status

This criterion is a measure of the TOMs current development status and availability for application. TOMs that are commercially available and have been applied on a full scale basis will score higher than TOMs that require extensive biological performance and engineering development.

5.1.2 Performance Certainty

This criterion is a measure of the anticipated need for extensive studies, modeling, or prototype testing to gain confidence in an alternative's anticipated performance with respect to sturgeon protection goals. TOMs that have demonstrated effectiveness as sturgeon deterrent or protection systems will score higher than TOMs that have fewer precedents or have demonstrated effectiveness on other species of fish but not sturgeon.

5.1.3 Nuclear Safety

This criterion is a measure of the TOM's consistency with US Nuclear Regulatory Commission safety and design requirement and the current permit conditions for SGS. Primary considerations include potential failure modes and a reduction in reliability of the service and circulating water systems.

5.1.4 Design Complexity

This criterion is a measure of the design complexity of the TOMs. TOMs that have complex designs are scored lower than those deemed to be relatively straightforward and can be installed in the near term with minimal engineering effort. This criterion considers the need for structural modifications, mechanical components, as well as hydraulic and structural complexity in the assessment.

5.1.5 Construction Complexity

This criterion is a measure of the construction complexity of the TOMs. Primary considerations include the need shutdowns or reduced flows, in-water work, impacts to other systems, and equipment access.

5.1.6 Permitting

This criterion is a measure of the level of permitting necessary to install the TOM. TOMs that do not require any permitting will be scored higher than TOMs that require in river work and associated state and federal permits.

5.1.7 Flexibility and Adaptability

This criterion is a measure of the potential for TOMs to be designed to allow modifications based on observed performance after construction and initial operation. TOMs that could be more readily modified are scored higher than those that will require substantial civil or mechanical work for future modifications.

5.1.8 Reliability and Redundancy

This criterion is a measure of the relative level of reliability and redundancy of the alternatives. TOMs that have fewer moving parts and mechanical systems are deemed to be more reliable and are scored higher. TOMs that can be provided with redundant systems are also scored higher.

5.1.9 Operation and Maintenance Complexity

This criterion is a measure of the anticipated intensity and complexity of routine operations and required maintenance. Passive systems are scored higher than systems that require manual operation. Systems with more mechanical components are scored lower than relatively static systems.

5.1.10 Impact on Existing CWIS Operations

This criterion is a measure of the potential for a TOM to affect CWIS operations. Considerations include the potential to affect the compliance with Section 316(b) of the Clean Water Act and the potential for the TOM to interfere with existing debris removal activities. TOMs that improve performance of the existing intake screens will score higher than TOMs that have a negative effect.

5.1.11 Life-Cycle Cost

This criterion is a measure of the relative life cycle cost of the TOMs. A qualitative assessment of costs will be used or the preliminary screening. Range-of-magnitude costs will be developed for TOMs that are carried forward to the detailed evaluation.

6.0 Initial Review and Screening of TOMs

6.1 Primary Screening

Alternative TOMs that have potential to reduce incidental take of sturgeon were assessed for application at the SGS circulating water intake as part of a preliminary screening. Based on the results of this screening, a determination was made whether to carry each TOM evaluated forward to a secondary screening (Table 6-1, located at end of this subsection). Each TOM was evaluated based on consideration of potential biological effectiveness and engineering feasibility. For a TOM to be considered biologically effective, available data and information were considered necessary to demonstrate that it has reasonable potential to reduce the take of sturgeon at the SGS intake. From an engineering standpoint, available information on each TOM needed to demonstrate it could be installed, operated, and maintained under the environmental and operating conditions experienced in the vicinity of the SGS intake.

For the preliminary screening, each TOM was qualitatively assessed for biological effectiveness, engineering feasibility, and to determine whether it had biological and/or engineering advantages over the other alternatives. For example, an intake technology that has been proven effective at reducing impingement and/or entrainment of a sturgeon species or for a wide range of fish species under a variety of intake conditions has a biological advantage over one that has been proven effective with only a limited number of species and intake types and conditions, or that has never been tested with sturgeon. From an engineering perspective, one TOM may hold an advantage over others if the civil/structural requirements for its installation are substantially less. To assist with determinations of biological effectiveness and engineering feasibility, screening criteria were developed to guide the review and assessment of each impingement reducing option. Additionally, Alden's scientists and engineers have extensive experience and knowledge on the application of existing fish protection measures at cooling water intakes (including for sturgeon species and at SGS), which allowed for informed decisions to be made on the biological and engineering feasibility of each TOM. This experience and knowledge, along with information and data specific to the sturgeon take issue at SGS that was provided by PSEG, also allowed Alden to develop several intake design modifications and operational measures that may reduce or eliminate sturgeon take.

The TOMs that were assessed in the preliminary screening were grouped by their mode of action and fall into one of five categories: behavioral barriers, physical barriers and collection systems, physical and operational measures, ice barrier modifications, and observational and preventative actions. Behavioral barriers alter or take advantage of natural behavior patterns to attract or repel fish. Physical barriers are designed to physically block fish passage and sometimes produce behavioral exclusion of fish small enough to pass through screening material. Collection systems are designed to actively collect fish for their return to a safe release location. Physical and operational measures include modifications to the existing trash rack, debris rake, and operation of the intake (including debris removal operations). Ice barrier modifications refer to structural or installation modifications to the ice barrier. Observational and preventative approaches include the use of technologies that monitor fish presence and movement at and in the vicinity of the intake to provide a warning prior to initiating operations (i.e., debris raking) that could lead to incidental take of sturgeon.

6.1.1 Behavioral Barriers

Behavioral barriers, also referred to as deterrents, function by producing a sensory stimulus that elicits an avoidance or attraction response from target species. Some behavioral barriers are designed to repel organisms away from an intake, whereas others have been used to attract fish to safe areas or towards a bypass. With a few exceptions, the biological effectiveness of behavior barriers has been low and/or mixed for most species evaluated. Consequently, there have been a limited number of behavioral deterrent technologies and applications of specific ones as permanent measures for reducing fish impingement and entrainment at water intakes in North America. In contrast, the use of behavioral barriers in Europe has been more prevalent, but effectiveness has not been evaluated for many of these applications or biological performance data is limited and/or unavailable for public review.

6.1.1.1 Sound

Sound deterrents include the transmission of infrasonic (< 100 Hz), sonic (100 Hz – 80 kHz), and ultrasonic frequencies (80 kHz) using various signal characteristics determined to be appropriate for a target species. Ultrasound has been found to effectively repel certain clupeid species only [including Alewife (*Alosa pseudoharengus*), Blueback Herring (*Alosa aestivalis*), American Shad (*Alosa sapidissima*), and Atlantic Menhaden (*Brevoortia tyyrannus*)], which have specialized hearing structures to detect ultrasonic frequencies. Evaluations of fish deterrence with infrasound have demonstrated limited effectiveness with European Eel and some salmonids. Infrasonic frequencies also have a very limited transmission range (less than 10 ft) for producing avoidance reactions, which would require a very large number of sound generators to provide sufficient coverage of large water intakes like that of SGS. Ultrasonic and infrasonic signals have not been tested with any sturgeon species, but the current knowledge of sturgeon hearing supports the conclusion that they cannot hear ultrasound. Sonic deterrents have produced mixed results with sturgeon, but some success has been achieved with boomers (204 dB re 1uPa peak at 20/min) indicating they could be effective at scaring sturgeon away from the trash racks prior to and during raking. Because boomers have been used to repel sturgeon from areas where they could be exposed to injury or mortality from in-river activities (e.g., blasting or pile driving), this technology was carried forward to the secondary screening of TOMs.

6.1.1.2 Light and Visual Keys

Various underwater light types have been shown to be effective deterrents or attractants for some fish species, including sturgeons. However, deterrent or attraction effectiveness has varied and, for some devices, there has been limited field testing (i.e., most evaluations have been conducted in a laboratory setting). The water turbidity in the vicinity of the SGS intake is very high, measured up to about 50 NTUs, which would potentially limit light penetration to about 6 ft from the source at levels expected to elicit behavioral responses from fish (this was measured for high intensity strobe light; other light sources, such as LEDs, may have even less penetration). Due to the high turbidity, applications of light or visual keys, such as shadows, would only be visible to fish in the very near field (i.e., within a few feet of the trash racks). This would limit the use of light as a deterrent or attractant and the use of visual keys for deterring or attracting sturgeon way from the trash rack. Consequently, it was concluded that light and other visual clues should not be carried forward to the secondary screening of TOMs.

6.1.1.3 Chemicals

Evaluations of carbon dioxide (CO_2) as a deterrent for certain fish species, such as Asian carps, have demonstrated some effectiveness. However, there is evidence that sturgeon are tolerant of high levels of CO_2, indicating this behavioral stimulus would not be an effective deterrent for sturgeon at the SGS intake. Other than CO_2, there are no other chemical attractants or deterrents that could be considered for reducing take of sturgeon. Consequently, this technology was not selected for the secondary screening of TOMs.

6.1.1.4 Electric Barriers

The electroreception sensory system of sturgeons is very effective at detecting weak electric field gradients. However, limited testing of sturgeon responses to electric barriers has not demonstrated high levels of avoidance. Therefore, electric barriers were not advanced to the secondary screening of TOMs.

6.1.1.5 Air Bubble Curtains

Air bubble curtains have not been evaluated as a method for excluding sturgeon at water intakes and testing with this behavioral stimulus has produced mixed effectiveness results with other species. A CFD model study was conducted for a full scale air bubble curtain designed for installation and operation at the SGS intake as part of an evaluation of several behavioral deterrents for their ability to reduce fish impingement. The model results determined that an air curtain could not be maintained as a barrier at the SGS intake due to high tidal velocities (ARL 2005). Due to lack of data demonstrating biological effectiveness and an inability to maintain an air bubble curtain at SGS, this technology was not included in the secondary screening of TOMs.

6.1.1.6 Bottom Sills

Sturgeon are benthic species that typically stay in close contact with bottom substrates. Therefore, using some type of bottom sill or barrier may have potential to block or guide sturgeon away from water intakes. However, there have been no lab or field evaluations of this technology concept with sturgeon however a bottom sill has been installed at the New Haven station to reduce impingement. At SGS, a bottom sill installed around the intake could be subject to considerable siltation due to the tidal currents and shifting bedload. Although there is limited biological effectiveness data and concerns regarding maintaining the integrity of a bottom structure, the bottom sill concept was carried forward to the secondary screening of TOMs because of its anticipated low costs.

6.1.1.7 Other Behavioral Barriers

Other behavioral barriers, such as water jets, hanging chains, and air burst systems have either not been tested or have had limited success as means to repel or prevent entrainment of fish, including sturgeons. However, these technologies may have potential as methods for producing startle and avoidance responses in sturgeon prior to or during raking operations and could potentially be combined with other TOMs to enhance avoidance responses. Consequently, each of these three alternatives was included in the secondary screening of TOMs.

6.1.1.8 Hybrid Deterrent Systems

Hybrid behavioral deterrent systems incorporate multiple stimuli as a method to increase deterrence at water intakes. Of the behavioral deterrents considered for reducing incidental take of sturgeon at SGS, a hybrid system that includes some combination of sound, water jets, hanging chains, and air burst systems could be beneficial. Based on potential for improved deterrence using multiple stimuli, hybrid systems were carried forward to the secondary screening of TOMs.

6.1.2 Physical Barriers and Collection Systems

Physical barriers consists of any technology or structure that physically blocks fish from entering an intake, whereas collection systems are applications that will actively collect fish and return them to a safe release location. Physical exclusion technologies (e.g., narrow-spaced bar racks or various types of fish screens) may also produce behavioral exclusion where fish small enough to pass through screen openings actively avoid entrainment. Physical barriers and collection systems have been successful at reducing entrainment and/or impingement of aquatic organisms at a wide range of water intake types, but effectiveness has varied based on site characteristics, hydraulic conditions, and species and life stages targeted for protection.

6.1.2.1 Fish-friendly Traveling Water Screens

Fish-friendly traveling water screens, similar to those currently installed downstream of the SGS intake trash racks, have the ability to collect impinged fish and return them safely to the source water. However, because fish are collected by these systems, any recovery of sturgeon with traveling screens would be considered an incidental take. Since this technology is already available at SGS and cannot feasibly be used as a first line of sturgeon take prevention (i.e., upstream of or at the current location of the trash racks), this technology was not considered for inclusion in the secondary screening of TOMs.

6.1.2.2 Barrier Net

Coarse-mesh barrier nets have been effectively applied at several hydropower projects and steam-electric cooling water intakes to reduce impingement and entrainment of juvenile and adult fish. When conditions are appropriate (i.e., low approach velocities and minimal debris loading), barrier nets have been an effective method for excluding fish from water intakes. Net mesh size is typically determined based on the smallest fish targeted for protection. Debris cleaning and biofouling control is often done manually with divers and can be labor-intensive (Michaud and Taft 1999; EPRI 2006). A barrier net at SGS would likely extend considerably out from the existing CWIS and require significant maintenance due to the significant debris loads in the vicinity of the intake. Consequently, a barrier net alternative was not included in the secondary screening of TOMs.

6.1.2.3 Cylindrical Wedgewire Screens

Cylindrical wedgewire screens are physical barriers that can effectively reduce impingement and entrainment at water intakes when designed appropriately. These screens can also create hydraulic exclusion for aquatic organisms when used in flowing water environments and oriented parallel with the prevailing flow direction. A combination of low through-slot velocity (≤ 0.5 ft/sec) and ambient cross-currents in the waterbody are typically required to carry less motile organisms (e.g., ichthyoplankton) and debris past the screens. The low through-slot velocity of these screens would require a large footprint at SGS due to the intake flow volume. A new intake would need to be constructed and likely extend a considerable distance into to the Delaware River Estuary. Consequently, this screen design would not be compatible with the existing intake at SGS. Based on this assessment, cylindrical wedgewire screens were not considered further as a TOM with potential for application specifically for reduction in sturgeon takes at SGS.

6.1.2.4 Louvers or Angled Bar Racks

Angled louvers and bar racks are an alternative to conventional trash rack designs that can be used to guide fish away from a water intake and, in the case of hydropower projects, towards a downstream bypass. These guidance technologies would require a major redesign of the SGS intake to reorient the bar racks (or install a louver array) for guidance of sturgeon away from the intake. However, the bidirectional tidal flow would make it difficult to provide sufficient protection across all tidal stages (optimal guidance flows approaching the structures could not be maintained for flow moving in both tidal directions). These technologies would also have similar debris loading considerations as the existing bar racks and a new debris removal system would need to be designed to handle the large amount of debris that is encountered at the SGS intake. This alternative does not have any advantage over the existing bar racks and would require a complete redesign of the existing intakes. Due to these shortcomings, louvers or angled bar racks were not carried forward to the secondary screening of TOMs.

6.1.2.5 Angled Screen

Angled screens are similar to louvers or angled bar racks but with smaller screen openings (typically wedgewire mesh with slot widths of 9.5 mm or less). Additionally, they can be angled horizontally or vertically to the intake flow. At SGS, angled screens would need to be paired with a trash rack or other wide spaced debris barrier, similar to the current arrangement with the existing traveling screens. Installation of angled screens at SGS would also require a new intake with an expanded footprint. For these reasons, angled screens are not carried forward to the secondary screening of TOMs.

6.1.2.6 Eicher Screens

The Eicher screen is a passive-pressure screen that has been proven effective for diverting fish in hydroelectric penstocks. Although biologically effective, Eicher screens are not designed for use at steam-electric cooling water intakes. Consequently, this technology was not included in the secondary screening of TOMs.

6.1.2.7 Modular Inclined Screens

Modular inclined screens (MIS) are a high-velocity inclined screen technology similar to Eicher screens, but designed for use at open intakes (i.e., not in penstocks). Laboratory and field studies have demonstrated effective diversion for a wide range of fish species (although, sturgeon have not been evaluated with this technology). Currently, the MIS technology has not been installed at a water intake. As a result, the potential for effective use as a method to reduce sturgeon take at SGS is unknown. Also, similar to other physical barriers and screening technologies, the construction of a new intake would be required for this type of screening system. Therefore, the MIS was not carried forward to the secondary screening of TOMs.

6.1.3 Trash Rack and Rake Modifications (Physical and Operational)

6.1.3.1 Trash Rack Modifications

There are several options for modifying the existing trash racks (operational and physical) that could potentially lead to reductions in the incidental take of sturgeon at SGS. These modifications include more frequent cleanings, replacing the trash rack with a non-metallic rack, and/or adding antifouling coating to the rack. These TOMs are intended to improve debris management and reduce biofouling of the rack in order to maintain it in a near-continuous clean condition. By improving the rack maintenance, hydraulic and intake design conditions that may contribute to sturgeon take have potential to be reduced or eliminated, including a reduction of velocities through the bar openings and pressure differentials across the trash rack. Consequently, modifications to the trash rack were carried forward to the secondary screening of TOMs.

6.1.3.2 Rake Modifications

There are several modifications to the rake and its operation for debris removal that could potentially reduce sturgeon take at the SGS intake. One operational approach would be to delay closing the rake prior to retrieval to allow sturgeon an opportunity to escape before becoming trapped. Installation of one or more behavioral deterrents (e.g., sound, water jets or spray, air burst system) to the rake could startle and repel sturgeon from the rack prior to raking. Water jets and an air burst system may also loosen debris and improve its removal.

Alternative rake designs could also be considered, including a rake that pushes on the down stroke, a continuous rack cleaning system, or a dedicated rake per bay. Rake designs that push on the down stroke would provide greater ability to move and clear debris as well as potentially startle sturgeon and allow them to escape vertically. However, there may be space limitations for this style of rake when the ice barrier is installed. Another option would be to install rakes at each intake bay to increase cleaning frequency. Due to the importance that a clean rack could have to reducing sturgeon take, rake modifications were carried forward to the secondary screening of TOMs.

6.1.4 Ice Barrier Modifications (Physical and Operational)

Modifications to the physical design of the ice barrier as well as the timing of installation have the potential to help reduce sturgeon take at the SGS intake. The ice barrier may be creating higher turbulence in the intake bay, which could be contributing to the increase in sturgeon take. Currently the ice barrier is installed from October until approximately mid-May. Ice is usually not an issue in the late fall or early spring, therefore the months that the barrier is installed could be reduced. In addition to reducing the amount of time the ice barrier is installed, escape ports could be added to allow sturgeon the ability to swim out through the ice barrier prior to the rake moving up. Another possible modification would be to increase the clearance between the barrier and the trash rake. This may provide space for fish to escape as the rake passes the ice barrier and reduce the upward velocity. For the reasons mentioned above, modifications to the ice barrier will be considered in the second screening.

6.1.5 Observational and Preventative

Observational and preventative measures implemented at SGS could be effective at reducing incidental take of sturgeon at SGS by providing a warning system for the presence of sturgeon at or in the vicinity of the trash racks prior to initiating raking operations. Observational techniques would include hydroacoustic monitoring of the trash racks to identify sturgeon targets. Differential water level sensors could also be deployed to provide more precise measurements of head loss and real-time remote monitoring indicating when raking should be conducted to maintain a clean rack on a near real-time basis. Thorough inspection and cleaning of the rack before ice barrier installation could also be conducted. These measures, or some combination of them, would inform operators of the presence of sturgeon and assist with maintaining a clean rack with hydraulic conditions that are less likely to lead to sturgeon take. Due to relative ease at which these approaches could be implemented and the potential benefits to reducing take, operational and preventative measures were carried forward to the secondary screening of TOMs.

6.1.6 Other Operational Changes

Changes in plant operation that reduce intake flow could potentially reduce sturgeon take at SGS. Such changes would require reduced pump operation (i.e., reduced generation load) or installation of a closed-cycle cooling system. The costs and impacts to generation would be substantial for these operational changes. Also, flow reductions were investigated in depth as part of the ongoing 316(b) compliance studies and concluded to not be feasible for entrainment and impingement reductions. Therefore, reduced flow alternatives were not included in the secondary screening of TOMs.

Table 6-1. Primary Screening of TOMs considered for the reduction of sturgeon incidental take at SGS. Highlighted alternatives were carried forward to the secondary screening.

Concept	Biological Effectiveness		Engineering Available	Advantages Over Other Concepts	Potential for Application with Other TOMs	Potential for Application at SGS	Consideration Notes
	Other Species	Sturgeons					
Behavioral Barriers							
Sound (100 - 10,000 Hz)	Yes	Limited	Yes	Yes	Yes	Yes	Effectiveness results have been mixed for a variety of species; previous testing for SGS demonstrated only low to moderate effectiveness for representative important species. However, studies with boomer have shown some effectiveness.
Ultrasound (>80 kHz)	Yes	No	Yes	No	No	No	Only effective with some clupeids (e.g., American Shad, Alewife, Blueback Herring).
Infrasound (< 100 Hz)	Limited	Unknown	Yes	No	No	No	Limited research and no information for sturgeon response.
Strobe Lights	Limited	Unknown	Yes	No	No	No	Turbidity at SGS is high and will limit range of effective light intensities to only a few feet.
Continuous Lights	Limited	Unknown	No	No	No	No	Turbidity at SGS is high and will limit range of effective light intensities to only a few feet.
Chemicals	Limited	Unknown	Yes	No	No	No	Sturgeon have relatively high tolerance to CO_2 which would reduce any potential for avoidance.
Electric Screens	Limited	Unknown	Yes	No	No	No	Electric deterrent studies have been limited with sturgeon with little or no avoidance.
Air Bubble Curtain	Limited	Unknown	Yes	No	No	No	CFD modelling of a full-scale air curtain at SGS's intake determined it could not be maintained due to high tidal velocities.
Water Jets	Limited	Unknown	Yes	Yes	Yes	Yes	Water jets may produce a startle or avoidance response to move sturgeon away from the prior to or during raking.

Table 6-1. (continued)

Concept	Biological Effectiveness		Engineering Available	Advantages Over Other Concepts	Potential for Application with Other TOMs	Potential for Application at Salem	Consideration Notes
	Other Species	Sturgeons					
Behavioral Barriers							
Air Burst System	Limited	Unknown	Yes	Yes	Yes	Yes	Air burst system operated prior to or during raking may produce startle or avoidance responses to move sturgeon away from rake; could also improve debris removal.
Hanging Chains	No	Unknown	Yes	Yes	Yes	Yes	Chains on rake may produce startle or avoidance responses to move sturgeon away from the rake during debris removal.
Visual Keys	No	Unknown	Yes	No	No	No	Turbidity at SGS is high and will limit range of effective light intensities to only a few feet.
Bottom Sill	Unknown	Unknown	Yes	Yes	Yes	Yes	Sturgeon are a benthic species and may be blocked or guide along a bottom barrier, Concerns with siltation and no information on effectiveness.
Hybrid Deterrents (e.g. sound/air bubble curtain)	Yes	Unknown	Yes	Yes	Yes	Yes	Sound in conjunction with water jets or hanging chains may increase deterrence effectiveness compared to standalone operation.
Physical Barriers and Collection Systems							
Fish-friendly Traveling Water Screens (fine and Coarse-mesh)	Yes	Yes	Yes	No	Yes	No	Would require new intake with traveling screens as first line of fish protection. Not feasible due to cost and debris issues.
Barrier Net In front of CWIS	Yes	Unknown	Yes	No	No	No	Large footprint in front of the CWIS. Flow velocity, ice, and debris concerns.
Cylindrical wedgewire screens (Wide and Narrow-Slot)	Yes	Yes	Yes	No	No	No	Not compatible with existing intake; rejected as for of 316(b) compliance due to ice and debris concerns.

Table 6-1. (continued)

Concept	Biological Effectiveness		Engineering Available	Advantages Over Other Concepts	Potential for Application with Other TOMs	Potential for Application at Salem	Consideration Notes
	Other Species	Sturgeons					
Physical Barriers and Collection Systems							
Louver System	Yes	Yes	Yes	No	No	No	Large footprint, new intake structure and debris removal system required.
Angled Screens	Yes	Unknown	Yes	No	No	No	Large footprint, new intake needed and potential for more debris issues.
Eicher Screen	Yes	Yes	No	No	No	No	Designed for hydroelectric penstocks; not applicable to cooling water intakes.
Modular Inclined Screen (MIS)	Yes	Unknown	No	No	No	No	Large footprint, new intake required and no performance data for sturgeon.
Trash Rack and Rake Modifications (Physical and Operational)							
More Frequent Cleaning	Unknown	Unknown	Yes	Yes	Yes	Yes	Reduce the pressure differential across the trash rack and keep the lower half of the rack clean. Uses existing equipment.
Delayed rake closing	Unknown	Unknown	Yes	Yes	Yes	Yes	Provides opportunity for fish to escape rake before becoming trapped and uses existing equipment.
Dedicated Rake Per Bay	N/A	N/A	Yes	No	Yes	Yes	Allows for more frequent cleaning across entire intake.
Rake Replacement (push on the down stroke)	N/A	N/A	Yes	Yes	Yes	Yes	Depending on model, can push through debris on the down stroke or rides over debris and starts lift at the bottom. May startle sturgeon on down stroke allowing vertical escape. There may be space limitations between rake and ice barrier
Continuous chain rake	N/A	N/A	Yes	Yes	Yes	Yes	Continuously cleans the trash rack; may be insufficient space between trash rack and ice barrier.

Table 6-1. (continued)

Concept	Biological Effectiveness		Engineering Available	Advantages Over Other Concepts	Potential for Application with Other TOMs	Potential for Application at Salem	Consideration Notes
	Other Species	Sturgeons					
Trash Rack and Rake Modifications (Physical and Operational)							
Replace the Trash Rack with none-metallic rack	N/A	N/A	Yes	Yes	Yes	Yes	Smooth material to reduce adhesion strength of biofouling. Eliminates corrosion, improved cleaning efficiency and reduced flow velocities through rack.
Antifouling coating on the Trash Rack	N/A	N/A	Yes	Yes	Yes	Yes	Smooth material to reduce adhesion strength of biofouling. Eliminates corrosion, improved cleaning efficiency and reduced flow velocities through rack.
Ice Barrier Modifications (Physical and Operational)							
Changes to Installation schedule	N/A	Unknown	Yes	Yes	Yes	Yes	Install later and remove earlier to eliminate conditions that may lead to sturgeon entrapment and collection during raking operations.
Add escape ports	Unknown	Unknown	Yes	Yes	Yes	Yes	Allow sturgeon to swim out though the ice barrier as the rake moves up.
Angle bottom outward	Unknown	Unknown	Yes	Yes	Yes	Yes	Increase the clearance between the ice barrier and the trash rack, reduced upward velocities that may be contributing to sturgeon entrapment during raking.
Observational and Preventative							
Acoustic monitoring prior to raking	N/A	Unknown	Yes	Yes	Yes	Yes	Identify sturgeon at trash rack and delay cleaning until they move or are repelled using behavioral deterrent.
Thorough inspection and removal of debris before ice barrier installation	N/A	N/A	Yes	Yes	Yes	Yes	Ensure the full trash rack and intake depth is debris free to reduce velocities and sub-optimal hydraulic conditions.
Add differential water level sensors	N/A	N/A	Yes	Yes	Yes	Yes	More precise differential measurements allows for remote monitoring and increased trash rack cleaning frequency.

Table 6-1. (continued)

Concept	Biological Effectiveness		Engineering Available	Advantages Over Other Concepts	Potential for Application with Other TOMs	Potential for Application at SGS	Consideration Notes
	Other Species	Sturgeons					
Operational							
Reduced intake flow	Yes	Unknown	Yes	No	No	No	Would reduce intake velocities. Would require reduced generation load. No advantages over improved trash rack cleaning. Was rejected as during 316(b) compliance technology review.
Closed-cycle Cooling	Yes	Yes	Yes	No	No	No	Would significantly reduce or eliminate sturgeon take. Would require major redesign of cooling system. Was rejected during 316(b) compliance technology review.

6.2 Secondary Screening

Based on the results of the preliminary screening, 21 TOMs were selected for assessment in the secondary screening phase. Up to five alternatives will be selected from the secondary screening for a further detailed evaluation of their potential application at SGS. These five alternatives may include combinations of the TOMs considered in the secondary screening. The result of the detailed evaluation will include recommendations for an alternative that can be installed and begin operation for sturgeon protection in the fall of 2020. Recommendations may also be provided for alternatives that are determined to have significant potential for providing effective protection and meet engineering feasibility and cost requirements, but will require additional time for design and deployment.

The secondary screening was a more in depth assessment of TOMs selected from the preliminary screening. A set of criteria was developed by Alden in consultation with PSEG for use in the secondary screening of the selected TOMS (see Section 5). The screening criteria were used to develop a relative quantitative scoring system to identify up to five TOMs to be included in the final detailed feasibility assessment. Throughout the preliminary and secondary screening process, the evaluation of TOMs was based primarily on available scientific literature (gray and peer-reviewed publications) and professional judgement, supplemented by some simple engineering calculations of hydraulic conditions at the intake.

The quantitative scoring system was used to rank each technology using the established screening criteria. An evaluation matrix was developed to provide a relative ranking of the selected alternatives using the screening criteria. The evaluation matrix was a valuable tool that focused the discussion of the alternatives within a defined structure relative to each screening criterion. The matrix and the quantitative scoring of TOM's is not meant to be the definitive selection methodology, but is useful for directing additional biological and engineering evaluation efforts.

6.2.1 Evaluation Criteria

For the secondary screening, the selected TOMS were evaluated based on the following criteria (see Section 5 for more detailed information on each criterion):

- Development Status
- Performance Certainty
- Nuclear Safety
- Design Complexity
- Construction Complexity
- Permitting
- Flexibility and Adaptability
- Reliability and Redundancy
- Operation and Maintenance Complexity
- Life-Cycle Costs

Each TOM was evaluated and ranked based on an assessment of each of criterion listed above (and described separately in the subsections below). A ranking value of 1 to 5 was given to each TOM for each criterion, where 5 indicates a TOM meets all conditions of a criterion and 1 indicates the TOM does not meet any conditions. A detailed description of each criterion and the factors that were considered in the scoring and ranking process are presented below. The rankings for each TOM were summed across the criteria and averaged. A final weighted score was calculated based on the relative importance of each criterion to identify which TOMs should be carried forward to the detailed feasibility assessment (i.e., up to five TOMs with the highest overall weighted scores).

6.2.1.1 Criteria Weights

The TOMS were ranked with both unweighted and weighted criteria. Unweighted criteria indicate that no criterion is more important than the other, which may not be the case. Weighting the criteria allows each criterion to be compared individually based on the importance to the other criteria. The weighted scores are used to aid in the determination of five TOMs for further consideration. The weights given to the screening criteria were developed based on discussions between the Alden and PSEG staff (Table 6-2). The unweighted alternative matrix is provided in Table 6-3 and the weighted alternatives matrix in Table 6-4. Both the unweighted and weighted matrices are color coded to provide a quick visual reference of where each TOM scores in relation to the other TOMs within a given criterion. The unweighted scores are color codes based on a score from 1 to 5; dark green represents a score of 5, light green is a score of 4, yellow is a score of 3, orange is a score of 2, and red a score of 1. The average unweighted scores and the weighed scores are based on a graded color scale where green hues represent higher scores with yellow, orange, and red hues representing progressively lower scores.

Table 6-2. Weightings calculated for screening criteria; higher weightings indicate greater importance.

Criteria	Weighting
Development Status	9
Nuclear Safety	11
Construction Complexity	13
Reliability and Redundancy	15
Life-Cycle Cost	17
Operation and Maintenance Complexity	19
Permitting	21
Performance Certainty	23
Flexibility and Adaptability	25
Design Complexity	27

Table 6-3. Unweighted secondary screening scoring matrix.

Category	TOM	Development Status	Performance Certainty	Nuclear Safety	Design Complexity	Construction Complexity	Permitting	Flexibility and Adaptability	Reliability and Redundancy	Operation and Maintenance Complexity	Life-Cycle Cost	Average Unweighted Score
Behavioral Barriers	Sound (100 - 10,000 Hz)	5	3	5	4	4	5	4	4	4	4	**4.2**
	Hybrid Deterrents (sound mounted on trash rake)	5	3	5	3	3	5	4	4	4	4	**4.0**
	Hybrid Deterrents (hanging chains mounted on trash rake)	4	2	5	4	3	5	3	3	4	5	**3.8**
	Hybrid Deterrents (Air burst mounted to trash rake)	4	3	5	2	3	5	3	3	3	3	**3.4**
	Hybrid Deterrents (water jets mounted on trash rake)	4	3	5	3	3	4	3	3	3	3	**3.4**
	Air Burst System	4	2	5	2	2	5	3	3	2	3	**3.1**
	Water Jets	4	2	5	3	2	4	3	3	2	3	**3.1**
	Bottom Sill	3	1	5	3	3	2	1	4	3	2	**2.7**
Trash Rack and Rake Modifications (Physical and Operational)	Delayed rake closing	5	3	5	4	4	5	3	4	5	5	**4.3**
	More Frequent and Improved Cleaning	5	4	5	5	5	4	2	4	4	4	**4.2**
	Rake Replacement (push on the down stroke)	5	4	5	4	4	5	2	4	5	2	**4.0**
	Dedicated Rake Per Bay	5	4	5	4	4	5	3	4	4	1	**3.9**
	New Rack with Continuous Rake	5	4	5	3	2	4	3	3	4	1	**3.4**

Table 6-3. (continued)

Category	TOM	Development Status	Performance Certainty	Nuclear Safety	Design Complexity	Construction Complexity	Permitting	Flexibility and Adaptability	Reliability and Redundancy	Operation and Maintenance Complexity	Life-Cycle Cost	Average Unweighted Score
Trash Rack and Rake Modifications (Physical and Operational)	Antifouling coating on the Trash Rack	4	2	5	4	2	4	2	3	2	3	**3.1**
	Replace the Trash Rack with none-metallic rack	5	2	3	3	2	3	1	3	5	2	**2.9**
Ice Barrier Modifications (Physical and Operational)	Modification to Installation and Removal Schedule	5	3	4	5	5	4	5	5	5	5	**4.6**
	Increase the clearance between the ice barrier and the trash rack	4	2	4	4	4	5	3	3	5	4	**3.8**
	Add escape ports	3	2	4	4	4	5	2	3	3	4	**3.4**
Observational and Preventative (not stand alone options)	Thorough inspection and cleaning before ice barrier installation	5	4	5	5	5	4	5	5	3	3	**4.4**
	Differential water level sensors	5	2	5	4	4	5	3	5	4	4	**4.1**
	Acoustic monitoring prior to raking	5	3	5	4	3	5	4	3	4	4	**4.0**

Table 6-4. Weighted secondary screening scoring matrix.

Category	TOM	Development Status	Performance Certainty	Nuclear Safety	Design Complexity	Construction Complexity	Permitting	Flexibility and Adaptability	Reliability and Redundancy	Operation and Maintenance Complexity	Life-Cycle Cost	Total Weighted Score
Weight		**9**	**23**	**11**	**27**	**13**	**21**	**25**	**15**	**19**	**17**	
Behavioral Barriers	Sound (100 - 10,000 Hz)	45	69	55	108	52	105	100	60	76	68	**738**
	Hybrid Deterrents (sound mounted on trash rake)	45	69	55	81	39	105	100	60	76	68	**727**
	Hybrid Deterrents (hanging chains mounted on trash rake)	36	46	55	108	39	105	75	45	76	85	**689**
	Hybrid Deterrents (Air burst mounted to trash rake)	36	69	55	54	39	105	75	45	57	51	**628**
	Hybrid Deterrents (water jets mounted on trash rake)	36	69	55	81	39	84	75	45	57	51	**622**
	Air Burst System	36	46	55	54	26	105	75	45	38	51	**574**
	Water Jets	36	46	55	81	26	84	75	45	38	51	**568**
	Bottom Sill	27	23	55	81	39	42	25	60	57	34	**480**
Trash Rack and Rake Modifications (Physical and Operational)	Delayed rake closing	45	69	55	108	52	105	75	60	95	85	**772**
	More Frequent and Improved Cleaning	45	92	55	135	65	84	50	60	76	68	**745**
	Rake Replacement (push on the down stroke)	45	92	55	108	52	105	50	60	95	34	**711**
	Dedicated Rake Per Bay	45	92	55	108	52	105	75	60	76	17	**689**
	New Rack with Continuous Rake	45	92	55	81	26	84	75	45	76	17	**620**

Table 6-4. (continued)

Category	TOM	Development Status	Performance Certainty	Nuclear Safety	Design Complexity	Construction Complexity	Permitting	Flexibility and Adaptability	Reliability and Redundancy	Operation and Maintenance Complexity	Life-Cycle Cost	Total Weighted Score
Weight		**9**	**23**	**11**	**27**	**13**	**21**	**25**	**15**	**19**	**17**	
Trash Rack and Rake Modifications (Physical and Operational)	Antifouling coating on the Trash Rack	36	46	55	108	26	84	50	45	38	51	**562**
	Replace the Trash Rack with none-metallic rack	45	46	33	81	26	63	25	45	95	34	**502**
Ice Barrier Modifications (Physical and Operational)	Modification to Installation and Removal Schedule	45	69	44	135	65	84	125	75	95	85	**804**
	Increase the clearance between the ice barrier and the trash rack	36	46	44	108	52	105	75	45	95	68	**668**
	Add escape ports	27	46	44	108	52	105	50	45	57	68	**604**
Observational and Preventative (not stand alone options)	Thorough inspection and cleaning before ice barrier installation	45	92	55	135	65	84	125	75	57	51	**776**
	Differential water level sensors	45	46	55	108	52	105	75	75	76	68	**766**
	Acoustic monitoring prior to raking	45	69	55	108	39	105	100	45	76	68	**722**

6.2.2 Development Status

This criterion is a measure of the TOMs current development status and availability for application. TOMs that are commercially available and have been applied on a full scale basis will score higher than TOMs that require extensive biological performance and engineering development.

After completing the screening of each alternative, the ranks given for development status were consistent through most of the alternatives, with each receiving scores of 4 or 5. TOM's that did not receive a score greater than 4, included the bottom sill and the ice barrier modifications (physical and operational). The reason these alternatives did not score as well is because they have not been fully tested either in an application similar to SGS or at any type of water intake, making their development status and performance uncertain.

6.2.3 Performance Certainty

This criterion is a measure of the anticipated need for extensive studies, modeling, or prototype testing to gain confidence in an alternative's anticipated performance with respect to sturgeon protection goals. TOMs that have demonstrated effectiveness as sturgeon deterrent or protection systems will score higher than TOMs that have fewer precedents or have demonstrated effectiveness on other species of fish but not sturgeon.

Most of the TOMs were assigned a moderate score for performance certainty. This is primarily due to a lack of data and information with respect to the biological performance of most of the alternatives with sturgeon species. However, some of the technologies have been proven to be effective with other fish species. Several of the behavioral barrier TOMs when considered for attachment to the trash rake scored high for these criteria due to their potential to startle or "scare" sturgeon, as well as the potential to combine several stimuli to increase deterrent effectiveness.

6.2.4 Nuclear Safety

This criterion is a measure of the TOM's consistency with US Nuclear Regulatory Commission safety and design requirement and the current permit conditions for SGS. Primary considerations include potential failure modes, a reduction in reliability, and potential for unplanned outages of the circulating water systems.

Every alternative, with the exception of trash rack replacement with non-metallic racks, was ranked high for this criterion because it was determined there were no or minimal nuclear safety concerns. The non-metallic rack replacement scored lower due to a higher probability of failure at lower differential pressures, which could lead to heavy debris loading on the traveling screens and rapid dewatering of circulating water pumps.

6.2.5 Design Complexity

This criterion is a measure of the design complexity of the TOMs. TOMs that have complex designs are scored lower than those deemed to be relatively straightforward and can be installed in the near term with minimal engineering effort. This criterion considers the need for structural modifications, mechanical components, as well as hydraulic and structural complexity in the assessment.

Many of the TOMs were ranked high in this category since they include relatively simple designs or easily implemented operational changes and will require minimal changes to the existing intake structures at SGS. For example, a thorough inspection and rack cleaning before deployment of the ice barrier in the late fall, more frequent debris removal, and adjustments to the ice barrier installation schedule (i.e., install later and remove earlier) all receive a ranking of 5 because of the ease of implementation. The new rack/rake options and most of the behavioral barriers, with the exception of sound and hanging chains on the trash rake, received lower rankings because they will require more design effort in order to incorporate them into the existing intake structure.

6.2.6 Construction Complexity

This criterion is a measure of the construction complexity of the TOMs. Primary considerations include the need for shutdowns or reduced flows, in-water work, impacts to other systems, and equipment access.

Similar to design complexity, many of the operational and preventative alternatives were given high rankings for this category because there is minimal or no construction required and they could potentially be implemented relatively quickly. The TOMs that require structural or physical modifications associated with a new trash rack, as well as behavioral barriers with an air burst systems, were ranked lower because they will require more time to install and will necessitate flow reductions during construction.

6.2.7 Permitting

This criterion is a measure of the level of permitting necessary to install the TOM. TOMs that do not require any permitting will be scored higher than TOMs that require in-river work and associated state and federal permits.

Most of the TOMs were ranked high for this criterion because they will not require extensive permitting to construct or implement. Installing a bottom sill scored considerably lower than other alternatives because it may require several permits from state and federal agencies. The replacement of the trash rack with a non-metallic rack also scored low because it may trigger a 10 CFR 50.59 nuclear safety study.

6.2.8 Flexibility and Adaptability

This criterion is a measure of the potential for TOMs to be designed to allow modifications based on observed performance after construction and initial operation. TOMs that could be more readily modified are scored higher than those that will require substantial civil or mechanical work for future modifications.

Modifications to the installation and removal schedule of the ice barrier (later installation and earlier removal) and conducting a thorough inspection and rack cleaning before installation of the ice barrier scored received rankings of 5 because of the ability to be flexible with both of these operational modifications based on their effectiveness at reducing take or impacts to station operation. Conversely, the bottom sill and replacement of the trash racks with non-metallic racks received a ranking of 1 because of their limited ability to be altered or modified after installation.

6.2.9 Reliability and Redundancy

This criterion is a measure of the relative level of reliability and redundancy of the alternatives. TOMs that have fewer moving parts and mechanical systems are deemed to be more reliable and are scored higher. TOMs that can be provided with redundant systems are also scored higher.

Changes to the installation schedule of the ice barrier, addition of differential water level sensors for initiating raking before too much debris accumulation occurs on the trash racks, and a thorough inspection and rack cleaning before ice barrier installation, all received a ranking of 5 for this criterion. These TOMs were ranked high because there would be no major reliability issues with their use and no requirements for redundancy. Other TOMs received lower rankings due to the use of moving parts and/or other equipment and materials that have greater potential for failure or need for periodic replacement.

6.2.10 Operation and Maintenance Complexity

This criterion is a measure of the anticipated intensity and complexity of routine operations and required maintenance. Passive systems are scored higher than systems that require manual operation. Systems with more mechanical components are scored lower than relatively static systems.

Water jets and air burst systems ranked lower for this criterion because they require significant power to operate and in the event of power loss they would not operate. Modifications to the installation schedule of the ice barrier, increase in clearance between the ice barrier and trash rack, and addition of differential water sensors to improve debris removal operations were all ranked high because they would require less operation and maintenance than the other TOMs.

6.2.11 Life-Cycle Costs

This criterion is a measure of the relative life cycle cost of the TOMs. A qualitative assessment of costs will be used for the preliminary screening. Range-of-magnitude costs will be developed for TOMs that are carried forward to the detailed evaluation.

The installation of chains on a new trash rake, delayed rake closing, and changes to the installation schedule of the ice barrier were all ranked high for this criterion because of they are expected to have low life cycle costs. The installation of a dedicated rake for each intake bay and installation of a new rack with a continuous raking all received rankings of 1 due to very high initial costs to install and long term costs to maintain their use at the SGS intake.

6.3 Advantages and Disadvantages of Each TOM Evaluated in the Secondary Screening

As described and presented in the previous section, the TOMs included in the secondary screening were ranked with respect to the screening criteria and unweighted and weighted averages of the criteria scores were calculated. This section provides an assessment of advantages and disadvantages that were considered when assigning criteria scores to each TOM. Within each category of alternatives, the TOMS are ordered based on their weighted score.

6.3.1 Behavioral Barriers

6.3.1.1 Sound (100-10,000 Hz)

Using sound to repel sturgeon away from the bar rack could potentially reduce incidental takes at SGS. Installation of a sound system in front of the intake has potential to limit sturgeon interactions with the intake, eliminating the risk of accidental take and impingement on the rack. Sound deterrents have been used in recent years to repel sturgeon from underwater blasting and dredging activities. Consequently, sound was carried forward to the next phase of the feasibility evaluation of TOMs. The general advantages and disadvantages of sound include the following:

Advantages

- Tested and applied at various facilities with a wide variety of fish species
- Utilized by USACE and approved by NMFS to deter sturgeon from blasting sites
- No nuclear safety concerns
- Sound frequency and magnitude can easily be adjusted if needed
- Limited moving parts
- Low power usage

Disadvantages

- Lack of rigorous evaluations of sturgeon responses to sonic frequencies
- Would require multiple transducers and extensive cabling to fully ensonify area in front of intake
- Would require pilot testing and sound mapping to determine effective frequencies and transducer locations
- Transducers and wiring can fail and would need periodic maintenance and replacement
- Occasional sound monitoring (measurements) would be required
- Most effective frequencies for sturgeon are unknown
- Potential impact on non-target species is unknown

6.3.1.2 Hybrid Deterrents (sound transducers mounted on a new trash rake)

This hybrid deterrent alternative would include one or more sound transducers mounted to the trash rack rake. This would allow a sound deterrent to ensonify rack areas immediately prior to and during raking in attempts to repel sturgeon from the path of the rake. This TOM is considered to have potential for effective operation and is being carried forward to the detailed evaluation phase. The general advantages and disadvantages that led to the positive scoring of this TOM include the following:

Advantages

- No nuclear safety concerns
- Surface based construction
- The sound frequency and magnitude can be adjusted
- Limited moving parts
- Lower power usage

Disadvantages

- This type of installation has not been tested; biological effectiveness unknown
- Movement of transducers and cabling on rake could cause damage and require excessive equipment maintenance and/or replacement

6.3.1.3 Hybrid Deterrents (hanging chains mounted on a new trash rake)

Hanging chains mounted to the trash rake are intended to startle and repel sturgeon away from the trash rack during raking operations. Movement and noise from the chains should produce an avoidance response from sturgeon in the path of the rake as it moves down over the trash rack. Hanging chains have not been tested with sturgeon, but are a low cost alternative with potential for effective operation. Consequently, this alternative has been carried forward to the detailed screening. The general advantaged and disadvantages used in determining these scores for this TOM include the following:

Advantages

- No nuclear safety concerns
- Minimal moving parts
- Surfaced based construction
- Ability to increase chain length and weight
- Deck based maintenance
- Low installation and O&M costs

Disadvantages

- Has not been tested for this type of application
- Potential for chains to get caught in rake or trash rack
- Potential for broken chains to foul traveling water screens

6.3.1.4 Hybrid Deterrents (air burst system mounted to a new trash rake)

This hybrid system includes an air burst system mounted to a new trash rake. This technology would send bursts of air down below the rake as it lowered for cleaning. The air bursts are expected to create visual, physical, and acoustic stimuli that elicit avoidance responses from sturgeon as the rake moves down the rack during the cleaning process. This TOM does not have any advantages over sound or hanging chains mounted to the trash rake. Consequently, it has not been carried forward to the detailed evaluation. The general advantages and disadvantages used in determining the criteria rankings for this TOM include the following:

Advantages

- Has been used at other water withdrawals for effective debris removal
- No nuclear safety concerns
- Surfaced based construction
- Can adjust frequency and pressure of air
- Less piping than standalone air bubble curtain option
- Deck based maintenance

Disadvantages

- No previous testing as a fish deterrent
- Would require large amount of air hosing and large compressors
- Many moving parts
- Moderate power usage

6.3.1.5 Hybrid Deterrents (water jets mounted on a new trash rake)

This hybrid system involves the use of water jets emitted from nozzles on the trash rake. This technology would direct high pressure streams of water below the rake as it moves down the rack during cleanings. The water jets should repel sturgeon away from the rack during debris removal. This TOM does not have any advantage over sound and hanging chains on the trash rack and, consequently, it has not been carried forward to the detailed evaluation. The general advantages and disadvantages used in determining criteria rankings for this alternative are the following:

Advantages

- Has been used at other water withdrawals to improve debris handling characteristics of cleaning mechanisms
- No nuclear safety concerns
- Surface based construction
- Less piping than standalone water jet option
- Location and pressures can be adjusted
- Deck based maintenance

Disadvantages

- Has not been used previously for fish deterrence
- May require significant infrastructure (hoses, pumps, etc.)
- May require additional permitting to discharge water in estuary
- Limited hydraulic capacity for jets
- Many moving parts

6.3.1.6 Air Burst System

An airburst system installed at the bottom of the trash rack could potentially be an effective method to startle and repel sturgeon that are in the vicinity of the intake trash rake prior to cleaning. This TOM has not been tested with sturgeon and does not have any advantage over a sound barrier. Consequently, this alternative was not carried forward to the detailed evaluation. The general advantages and disadvantages that led to the criteria rankings for an air burst system are the following:

Advantages

- No nuclear safety concerns
- Moderate cost and power usage
- Can adjust frequency and pressure
- May loosen debris from the rack

Disadvantages

- Has not been tested with sturgeon
- May require significant infrastructure (air hoses, receivers, compressor, etc.)
- Moderate power usage
- Many moving parts
- Diver based inspections to maintain submerged equipment
- Moderate initial cost but there would high be annual O&M costs

6.3.1.7 Water Jets

Water jets installed at various depths near the face of the intake could be used to repel sturgeon away from the intake prior to debris removal. This alternative would require a significant construction effort, as well as ongoing O&M to maintain the nozzles and associated water pumps. As a result of these shortcomings, this technology was not carried forward to the detailed evaluation phase. The general advantages and disadvantages of water jets include the following:

Advantages

- No nuclear safety concerns
- Locations and pressures of the jets can be adjusted

Disadvantages

- Limited evaluations of effectiveness, have not been tested with sturgeon or at cooling water intakes
- May require significant infrastructure (hoses, pumps, etc.)
- May need divers and reduced flows during installation
- May require additional permitting to discharge water in estuary
- Many moving parts
- Diver based inspections to maintain submerged equipment
- High initial and annual O&M costs

6.3.1.8 Bottom Sill

A bottom sill installed at a distance around the SGS intake could be used to guide and/or block sturgeon from the intake. This technology assumes most sturgeon approach the intake near the river bottom and would not rise and pass over the structure. Due to limited ability to maintain a bottom sill (i.e., due to sedimentation buildup) and the potential for fish to pass over the structure, this technology was not carried forward to the detailed evaluation. The general advantages and disadvantages that led to the criteria rankings for this alternative include the following:

Advantages

- No nuclear safety concerns
- Few moving parts
- Laboratory study indicates potential for sturgeon guidance

Disadvantages

- Not specifically developed for this type of application
- Sturgeon could potentially swim up in the water column and over the sill
- Permits may be required for construction in estuary
- Limited ability to modify once constructed
- High initial cost and repeated diver costs for cleanings
- Heavy sedimentation rates at SGS would be expected to quickly fill void in front of sill and eliminate any potential benefits

6.3.2 Trash Rack and Rake Modifications (Physical and operational)

6.3.2.1 Delayed Rake Closing

Delayed closing of the rake before collecting debris would provide sturgeon an opportunity to escape and avoid being trapped in the rake claw. This alternative would not require any additional equipment and could be easily implemented. Consequently, this operational modification was carried forward to the detailed screening evaluation. The general advantages and disadvantages that led to the criteria rankings of this alternative include the following:

Advantages

- Allows sturgeon to escape before the rake claw is closed and lifted to the surface
- No nuclear safety concerns
- Open duration on rake can be adjusted based on initial results and sturgeon interaction observations

Disadvantages

- Sturgeon may become entangled in debris during downward movement of rake and eventually collected and brought to the surface
- Raking system may need to be reprogrammed
- Limited effectiveness if sturgeon are not startled by rake lowering

6.3.2.2 More Frequent and Complete Cleaning

More frequent and complete (vertical) cleaning of the trash rack could improve hydraulic conditions at the rack face and reduce attraction of sturgeon that may be feeding in debris accumulated on the rack. This modified operational approach would create lower velocities at the rack, potentially reducing the potential for impingement and give sturgeon improved ability to swim away from the rack and avoid the rake. This TOM would not require any new equipment. Due to potential to be biologically effective and ease of implementation, this alternative has been carried forward to the detailed evaluation. The general advantages and disadvantages for this TOM include the following:

Advantages

- Applied and tested at various facilities
- No additional capital expense
- Cleaner rack would lower velocities and provide fish more opportunity to escape
- No nuclear safety concerns

Disadvantages

- Limited cleaning rate with existing equipment
- Increased wear on rake and rack
- Additional power needed
- Increased man power and labor needed to complete additional cleaning

6.3.2.3 Rake Replacement (push on the down stroke)

Replacement of the existing rakes with a new rake design that pushes into the debris on the down stroke would make cleaning of the rack more thorough and complete. The type of rake should be able to push through the debris and reach the bottom of the rack, allowing the entire depth of the rack to be effectively cleaned. This technology does not have any advantages when compared to increased cleaning frequency with the existing rake and, consequently, was not carried forward to the detailed evaluation. The general advantages and disadvantages of this alternative include the following:

Advantages

- Applied at various types of water intake structures
- A rake that pushes down has the ability to clean more of the rack than the exiting rake which uses gravity to be lowered

- Cleaner rack would produce lower velocities and provide fish more opportunity to escape
- No nuclear safety concerns
- No redesign of rack required

Disadvantages

- Requires new raking system
- Limited cleaning rate
- Moderate initial costs
- Heavy debris loading on trash bars could make this infeasible

6.3.2.4 Dedicated Rake per Bay

This TOM involves the installation of a dedicated rake per bay of the intake. This would make the cleaning process more efficient resulting in a cleaner rack. This TOM would have a high initial cost and does not have any advantages when compared to increased cleaning frequency with the existing rake. Consequently, this alternative was not carried forward to the detailed evaluation. The general advantages and disadvantages of this TOM include the following:

Advantages

- Better debris handling capabilities may result in cleaner rack and improve hydraulic conditions and pumping operations
- Cleaner rack would lower velocities and provide sturgeon more opportunity to escape during racking operations
- No nuclear safety concerns

Disadvantages

- Limited space for installation of a rake at each bay
- Limited space for debris once raked off the rack
- Can only adjust cleaning frequency after installation
- Would require additional power
- High initial cost
- Current intake configurations would require the debris hopper be moved to either end of intake for removal of collected debris

6.3.2.5 New Rack with Continuous Rake

Installation of a new rack with a continuously operating rake would allow the trash rack to be maintained with less debris accumulation. Modifying the existing intake to accommodate this type of rake would have a high initial cost and would only provide a marginal increase in cleanliness compared to increased cleaning frequency with the existing rake. Consequently, this alternative was not carried forward to the detailed screening evaluation. The general advantages and disadvantages of this TOM include the following:

Advantages

- Applied to various types of water intakes
- Cleaner rack would produce lower velocities and provide fish more opportunity to escape
- No nuclear safety concerns
- Continuous cleaning

Disadvantages

- Requires replacement of both the rack and the rake
- Limited space for installation
- Replacement of the entire rack would require divers and reduced intake flows
- Lots of submerged moving parts
- High initial cost

6.3.2.6 Replace the Trash Rack with Non-metallic Rack

Replacement of the existing trash rack with a non-metallic rack would eliminate corrosion and reduce biofouling. This should increase cleaning efficiency of the existing rake and reduce flow velocities at the rack. However, the level of improvement of cleaning efficiency provided by a non-metallic rack is unknown and is not expected to provide a significant advantage when compared to increased cleaning frequency with the existing rack and rake. Consequently, this TOM was not carried forward. The general advantages and disadvantages that determined criteria scores for this alternative include the following:

Advantages

- Has been applied at various types of water intakes, but are unaware of any application at nuclear fueled facilities
- Eliminates corrosion
- Reduces adhesion strength of bio growth
- Cleaner rack would produce lower velocities and provide fish more opportunity to escape

Disadvantages

- New rack may fail at lower differential pressure than existing rack
- Need to evaluate structural strength of rack
- Replacement of the entire rack would require divers and reduced intake flows
- Might result in nuclear safety concerns
- Unable to modify after installation

6.3.2.7 Antifouling Coating on the Trash Rack

Adding antifouling coating to the trash rack would reduce corrosion and biofouling on the rack, which is expected to increase the cleaning efficiency of the rake. The effect of an antifouling coating on cleaning efficiency is unknown and is not expected to provide significant advantages when compared to increased cleaning frequency with the existing rack and rake. Consequently, this alternative was not carried forward to the detailed evaluation. The general advantages and disadvantages for this TOM include the following:

Advantages

- No nuclear safety concerns
- Reduces corrosion
- Reduces adhesion strength of bio growth
- Cleaner rack would produce lower velocities and provide fish more opportunity to escape

Disadvantages

- Rack may need to be removed in order to install, requiring divers and flow reductions
- May need to prove coating would not impact water quality
- Would require periodic recoating

6.3.3 Ice Barrier Modifications (Physical and Operational)

6.3.3.1 Modification to Installation and Removal Schedule

Incidental take of Atlantic Sturgeon at SGS occurs primarily during the period when the ice barrier is attached to the intake. Although this may be due in part to sturgeon use of the estuary habitats in the vicinity of SGS during early winter through spring, the ice barrier may also produce physical and hydraulic conditions that make it difficult for sturgeon to escape from the path of the rack during debris removal operations. The negative effects of the ice barrier may be further increased by difficulty with complete debris removal from the lower part of the trash racks. Modifying the installation and removal schedule of the ice barrier (later installation and earlier removal) may be beneficial. Due to the potential biological benefits and ease of implementation, this alternative has been carried forward to the detailed evaluation. The general advantages and disadvantages of this operational change include the following:

Advantages

- Operational changes only, no physical modifications
- No construction necessary
- Can adjust based on weather each year
- Absence of ice barrier during periods of increased sturgeon abundance may improve ability for sturgeon to move away from trash bars during raking activities

Disadvantages

- Removal of ice barriers may contribute to increased debris loading on the trash bars.
- Increased debris loading on trash bars may result in need for additional cleaning or adversely impact operations

- Uncertainty regarding impact of ice barrier presence on sturgeon incident takes

6.3.3.2 Increase Clearance between the Ice Barrier and the Trash Rack

Increasing the clearance between the ice barrier and the trash rack may provide better conditions for sturgeon to swim under the ice barrier and away from the rack as the rake moves down the rack (i.e., reduce the potential for sturgeon to become trapped behind the ice barrier and be collected by the rake). This TOM is not expected to provide any significant advantages when compared to reducing the time period when the ice barrier is installed. Consequently, it was not carried forward to the detailed evaluation. The general advantages and disadvantages of this TOM include the following:

Advantages

- Limited modifications once the ice barrier is installed each year

Disadvantages

- No information on potential effectiveness
- Velocities and debris still need to be managed
- May allow for larger ice pieces to pass by the barrier
- Requires a redesign of the existing ice barrier
- Uncertainty regarding impact of ice barrier presence on sturgeon incident takes

6.3.3.3 Installation of Escape Ports in the Ice Barrier

The installation of escape ports in the ice barrier may provide increased opportunities for sturgeon to swim through the barrier thereby preventing them from becoming trapped between the ice barrier and the trash rack as the rake collects debris. However, hydraulic and debris loading conditions at escape ports may limit the ability of sturgeon to successfully exit the ports and this approach is not expected to provide a significant advantages when compared to reducing the time period when the ice barrier is installed. Consequently, this alternative was not carried forward to the detailed evaluation. The general advantages and disadvantages of this TOM include the following:

Advantages

- May provide opportunity for fish trapped above the rake to escape when ice barrier is present

Disadvantages

- No information on potential effectiveness
- Velocities and debris still need to be managed
- May allow for larger ice pieces to make it through the barrier
- Required inspection and debris removal of escape ports when ice barrier is installed
- Requires a redesign of the existing ice barrier
- Removal of ice barriers may contribute to increased debris loading on the trash bars.

- Increased debris loading on trash bars may result in need for additional cleaning or adversely impact operations
- Uncertainty regarding impact of ice barrier presence on sturgeon incident takes

6.3.4 Observational and Preventative

Observational and preventative measures are not stand alone alternatives, but should be considered as potential enhancements when combined with other TOMs.

6.3.4.1 Thorough Inspection and Cleaning before Ice Barrier Installation

A thorough inspection and debris cleaning of the trash racks before the installation of the ice barrier would reduce or eliminate poor hydraulic or debris loading conditions that may lead to sturgeon take after the ice barriers are in place. This TOM would be combined with a method to maintain the rack in a clean condition to lower velocities along the rack and eliminate conditions that reduce ability of sturgeon to evade capture by the rake during debris removal. Consequently, this TOM has been carried forward to the detailed evaluation. The general advantages and disadvantages of this alternative include the following:

Advantages

- A cleaner rack would have lower velocities and provide more opportunity for fish to escape
- Underwater inspections would ensure the trash rack is as clean as possibly before going into the winter season
- No nuclear safety concerns
- No construction required
- Timing and frequency of inspections and cleaning can be easily modified

Disadvantages

- May need permits if dredging is required to clear debris and sediment at base of trash rack
- Divers or hydroacoustic imaging required for rack inspection

6.3.4.2 Hydroacoustic Monitoring Prior to Raking

Hydroacoustic monitoring for sturgeon presence in the vicinity of the intake and at the trash rack before raking could be used to determine the effectiveness of a TOM, to implement a deterrent measure, and/or allow operators to postpone raking until the absence of sturgeon can be verified. Consequently, hydroacoustic monitoring has been carried forward to the detailed evaluations of TOMs. The general advantages and disadvantages of this alternative include the following:

Advantages

- Recent studies conducted at SGS indicate sturgeon can be identified in vicinity of intake and at the trash racks using available sonar technologies
- Would be able to identify sturgeon prior to raking

- No nuclear safety concerns
- Can adjust location and monitoring methods
- Limited installation requirements

Disadvantages

- Would need to be combined with one or more other TOMs to prevent take (i.e., a behavioral deterrent or other measure that causes sturgeon to leave trash rack area)
- May be difficult to get complete coverage of the entire rack
- Pilot testing likely needed to resolve logistics

6.3.4.3 Differential Water Level Sensors

Adding differential water sensors to measure the pressure differential across the trash rack could lead to improved debris removal operations. The installation of differential sensors would indicate the magnitude of debris loading on the rack. However, the ability to clean the rack would still be limited by the rake itself; as such, this TOM does not have any advantages over increased cleaning of the rack and it was not carried forward to the detailed evaluation. The general advantages and disadvantages of this alternative include the following:

Advantages

- Has been tested and applied at various types of water intakes
- A cleaner rack would allow more opportunity for fish to escape
- No nuclear safety concerns
- Relatively straight forward installation (2 sensors per bay)
- Can easily adjust cleaning schedule based on pressure sensor readings
- Limited installation requirements

Disadvantages

- Needs to be paired with another TOM for increased cleaning frequency
- Potential equipment reliability issues due to harsh installation environment

6.3.5 Alternatives Recommended for Detailed Evaluation

Based on the scoring of each TOM included in the secondary screening and the best professional judgement of PSEG and Alden staff, the following TOMs have been carried forward to the detailed feasibility evaluation:

- Sound deterrent installed at the intake or deployed as mobile system adjacent to trash rake
- Hanging chains mounted to the trash rake
- More frequent cleaning of the rack with delayed closing of the rake
- Modified ice barrier installation and removal schedule (later installation and earlier removal)

- Hydroacoustic monitoring of the intake and trash rack to assess TOM effectiveness and to determine presence/absence of sturgeon prior to initiating raking operations

With the exception of hydroacoustic monitoring, the above TOMs will be considered for potential application at the SGS intake as standalone measures and for use in combination with other alternatives as appropriate. Hydroacoustic monitoring will be considered as an evaluation and enhancement measure for the other alternatives.

7.0 Detailed Evaluation of Selected TOMs

This section presents a detailed feasibility evaluation and assessment of the five TOMs determined to have the greatest potential for application at the SGS CWIS to reduce incidental take of sturgeon based on the results of the primary and secondary screenings. The selected TOMs are considered to have engineering, design, and/or O&M advantages over other alternatives that were included in the preliminary and secondary screenings. The five alternatives selected for detailed evaluation are:

- Sound deterrent installed at the intake or deployed as mobile system adjacent to trash rake
- Hanging chains mounted to the trash rake
- More frequent cleaning of the rack with modified rake speed and delayed closing of the rake
- Modified ice barrier installation and removal schedule
- Hydroacoustic monitoring of the intake and trash rack to assess TOM effectiveness and to determine presence/absence of sturgeon prior to initiating raking operations

Several of these TOMs are combinations of individual TOMS identified in the secondary screening. These TOMS were combined because they are either sufficiently similar to another TOM or because they complement each other. The five TOMs considered for potential application at the SGS intake can be used as standalone measures or in combination with other alternatives as appropriate. Hydroacoustic monitoring is not being considered as a standalone option but rather as an evaluation and enhancement measure for the other alternatives.

The detailed conceptual designs presented in this section account for site-specific engineering considerations, including some that were not considered in the preliminary and secondary screenings. Available literature and best professional judgment were used for the selection and design of these TOMs, but none of the TOMs have been installed or evaluated as a fish protection measure for reducing incidental take of Atlantic Sturgeon (or other sturgeon species) at a water intake. Because of the unique conditions at SGS and limited, if any, field deployments or applications of these technologies, there is a uncertainty associated with the biological effectiveness of each alternative. These uncertainties are discussed in the detailed assessment of each alternative. Additional pilot studies that may be needed to determine the best way to deploy a TOM or to mitigate the uncertainties and risks are also discussed.

7.1 Sound Deterrent Installed at the Face of the Intake or Deployed Adjacent to Trash Rake

There are two potential sound deterrent deployment alternatives considered for application at the SGS: (1) sound transducers mounted on the intake and (2) sound transducers deployed adjacent to the trash rakes using a mobile system. Sound transducers mounted to fixed structures, such as intake piers, have been installed and tested at a number of facilities for fish species other than sturgeon. Mounting sound transducers to moving equipment has not been applied at other facilities and is considered a novel application of this technology.

7.1.1 Design and Construction

A sound barrier system installed at SGS would use wide beam transducers to produce a sound field that covers a relatively large area for both mounting options considered for deployment. Based on previous studies and applications, sturgeon may be able to hear frequencies from 100 Hz to 1,000 Hz (Popper 2005). Lovell et al. (2005) reported that Lake sturgeon were responsive to sound signals ranging in frequency from 100-500 Hz, whereas Meyer et al. (2010) found sturgeon responses occurred at frequencies between 50 and 100 Hz. Using ABR (auditory brainstem response) electrophysical response testing, Lovell et al. (2005) determined the lowest sound pressure threshold was about 118 dB at 200 Hz when particle motion was dominating and 122 dB at 200 Hz when sound pressure was dominating. Transducers that can produce frequencies as low as 100 Hz at source levels of 190 dB re 1 micro pascal (µPa) at 1 m were assumed for the detailed evaluation of the sound deterrent alternatives. However, additional research is needed before finalizing the frequencies and sound levels of the transducers.

7.1.1.1 Sound Deterrent Installed at the Face of the Intake

This TOM alternative would use transducers mounted to the face of the intake to create a "wall" of sound encompassing the entire intake and extending some distance into the river to repel sturgeon away from the trash racks. The proposed spacing of the sound transducers is considered preliminary and would depend on the type and model of transducer selected and the sound signal characteristics. The transducer arrangement presented was selected to create a full width and depth sound deterrent field with a minimum sound pressure level (SPL) of approximately 160 dB. An SPL of 160 dB was selected because it is almost 40 dB above the minimum sound threshold for which a sturgeon species responded (Lovell et al. 2005). SPLs will remain below 200 dB so as to not approach the levels that can cause injuries. This is based on the study by Halvorsen et al. (2012) that was used for the sturgeon sound exposure guidelines for the Acoustical Society of America, which found mild injuries in sturgeon beginning at 204 dB (Popper et al.2014). While a vendor did provide a conceptual design for the site, more information and discussions with other vendors is needed. Therefore, selection of appropriate transducers and acoustic modeling of the sound field would need to be completed before finalizing the sound deterrent configuration.

Based on the SPL requirements and expected propagation of the most effective frequencies, four transducers would be required to ensonify the entire intake. These transducers would be mounted to the face of the CWIS and intake bay divider walls (Figure 7-1). Each of these sound transducers would be placed halfway between the top deck and invert of the CWIS at elevation 75 ft (Figure 7-2). The 170 dB SPL is estimated to extend approximately 30 ft out from each transducer and the 160 dB SPL about 100 ft (Figure 7-1, Figure 7-2). Although not shown, an SPL greater than 150 dB would extend approximately 230 ft beyond the 160 dB contour and should be audible to sturgeon at this distance.

Each transducer would contain all the equipment necessary for signal generation, amplification, and transmission. The sound barrier would be operated from control panels located within the screen house. A separate controller would be installed for each unit to limit the length of the cables to the transducers. This arrangement also allows one sound system to be taken off line for service while maintaining protection for the remaining bays. Power cables would run under the trash rake rails. The entire sound barrier would be powered by SGS's in-house power system.

An amplifier, signal generator, computer control system, and cabling would be installed at a location above water and could be installed without impacting station operations. Divers would be required to install vertical guide rails to the face of the CWIS. These guide rails would allow each transducer to be lifted to the surface for inspection and maintenance. Following installation of the guide rails, the sound transducers and retrieval cabling would be deployed. Either a barge mounted retrieval system or a crane from shore (i.e., similar to the one used to deploy and retrieve the ice barriers) would be required to remove and redeploy the transducers following inspections and servicing. Divers would be used to verify the initial placement of the sound transducers. Installation of the sound system is expected to take less than one month.

After the system is installed and operational, sound field measurements (frequency detection and SPLs) would be conducted to validate the acoustic model used to select the locations of the transducers and to determine if there are any areas where the sound field may not be of sufficient amplitude (e.g., SPLs less than about 160 dB).

7.1.1.2 Mobile Sound Deterrent Transducer Deployed Adjacent to Trash Rake

For this alternative, a sound transducer would be mounted on a mobile cart with a telescopic arm that can be moved between intake bays (Figure 7-3). This layout was selected over mounting transducers directly to the trash rake to allow the sound transducer to be moved independently of the trash rake. Additionally, mounting a transducer directly to the rake would subject it to debris damage and require a redesign of the trash rake lifting roller drums to accommodate the transducer cables.

The mobile sound cart would allow the sound transducer to be moved between intake bays and lowered into place without interfering with rake operations. The sound transducer would be mounted to a rigid lifting rod with a telescopic arm and placed in a floating housing allowing it to potentially reach the bottom. Several minutes prior to raking, the transducer would be lowered to the water surface to scare fish away from the trash rack. The transducer would remain in the intake bay throughout the duration of the cleaning. The transducer would then be raised and moved to the next bay with the trash rake.

As described for the installation of transducers on the face of the intake, a cart-mounted transducer would produce an SPL of 160 dB or greater enveloping each bay and the trash rack. This type of deployment has not been tested and would require acoustic modeling of the sound field to determine the approximate area of sound ensonification at the required sound pressure levels and the level of attenuation or disruption in the sound field caused by the rake, bar rack, and debris.

The sound system controls would be located within a weathertight enclosure mounted directly to the mobile cart. Power to the sound system may be pulled from existing station power.

Construction of the mobile cart and sound system would be completed off site. The cart would then be brought onsite and rolled on to the intake deck. Once the system is on-site and operational, sound field measurements should be collected to verify frequency output and SPLs and, if necessary, refine the location and angle of the transducer.

7.1.2 Operation and Maintenance

The sound deterrent system could be installed and operated year round or just seasonally for when the sturgeon are in the vicinity. The fixed-mounted transducers would operate continuously, whereas a cart-mounted mobile system would only operate when the rack is cleaned. After installation is completed of the fixed system, the transducers would be inspected regularly to remove any biofouling and debris that may impair transducer performance and sound generation. The fixed-mounted transducers should be inspected no less than monthly, with more frequent inspections during heavy debris or bio growth seasons. The face of the intake is not accessible from the CWIS itself. As a result, boat, diver, or barge based inspections and maintenance of the sound transducers would be necessary.

The cart-mounted transducer should be inspected prior to operation of the trash rake. These inspections would be conducted from the deck. For cost considerations, it should be assumed that approximately 5% of the sound transducers and ancillary equipment would need to be replaced annually with both options.

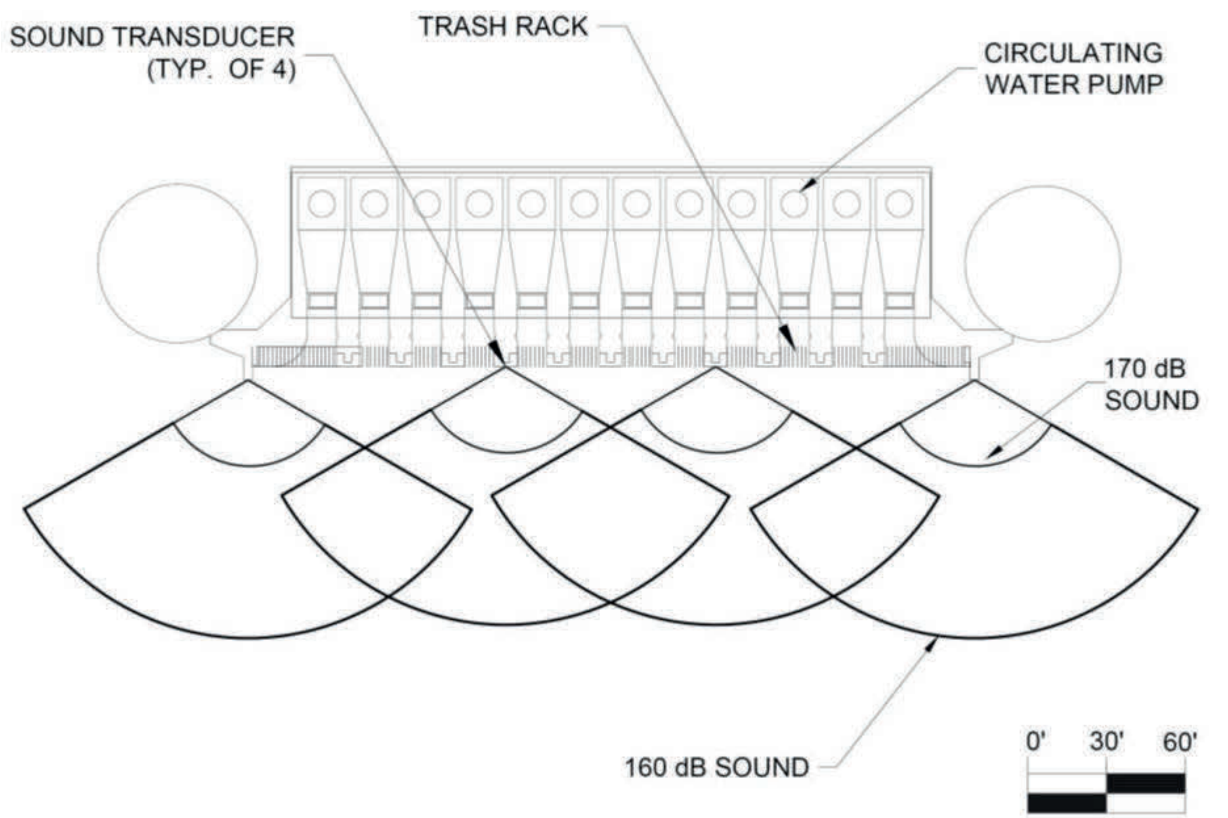

Figure 7-1. Conceptual layout of a sound deterrent installed at the face of the intake – plan view. Depiction of sound field is for demonstration purposes only and not based on actual data or modeling.

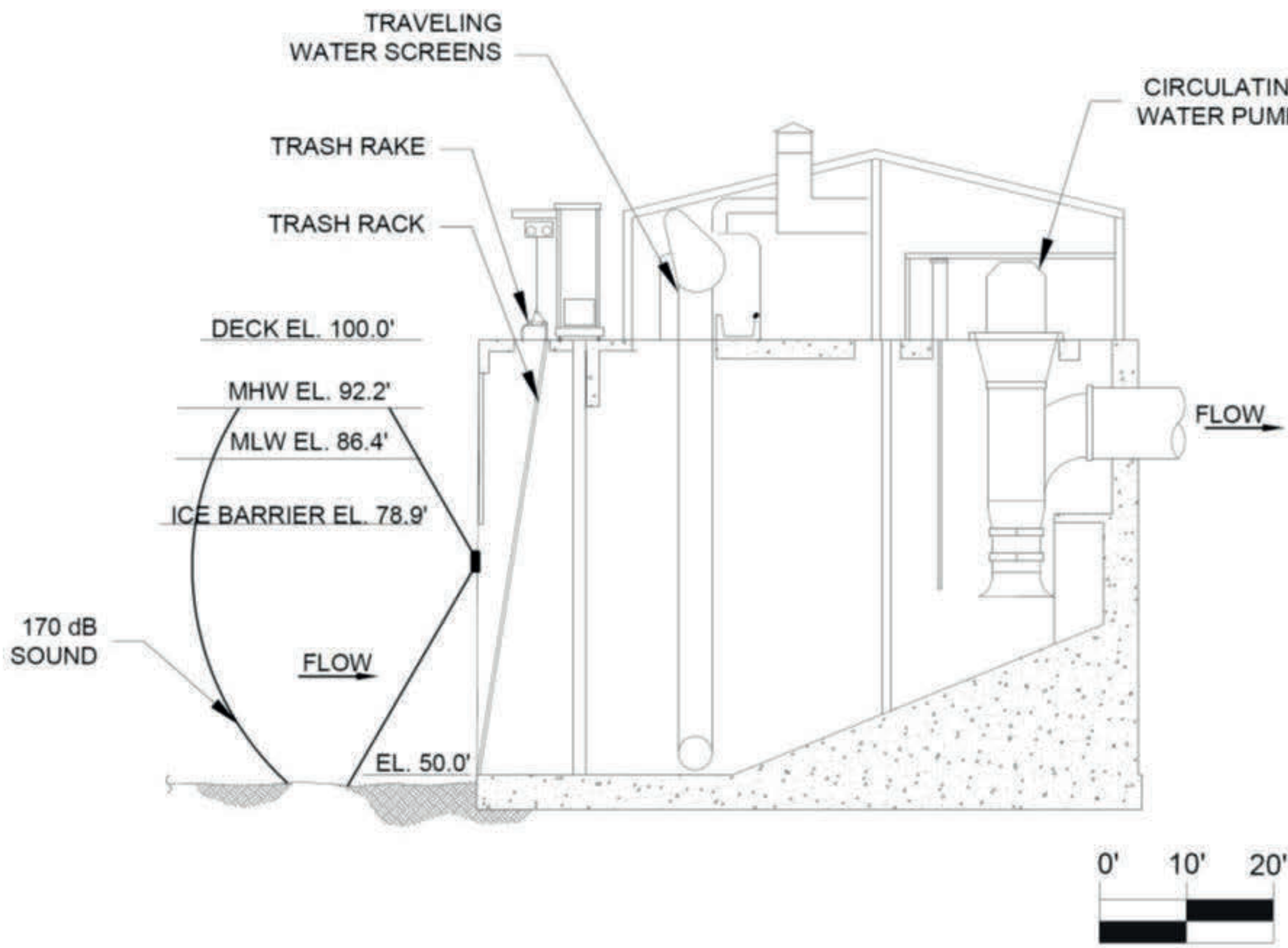

Figure 7-2. Conceptual Layout of a sound deterrent installed at the face of the intake – elevation view. Depiction of sound field is for demonstration purposes only and not based on actual data or modeling.

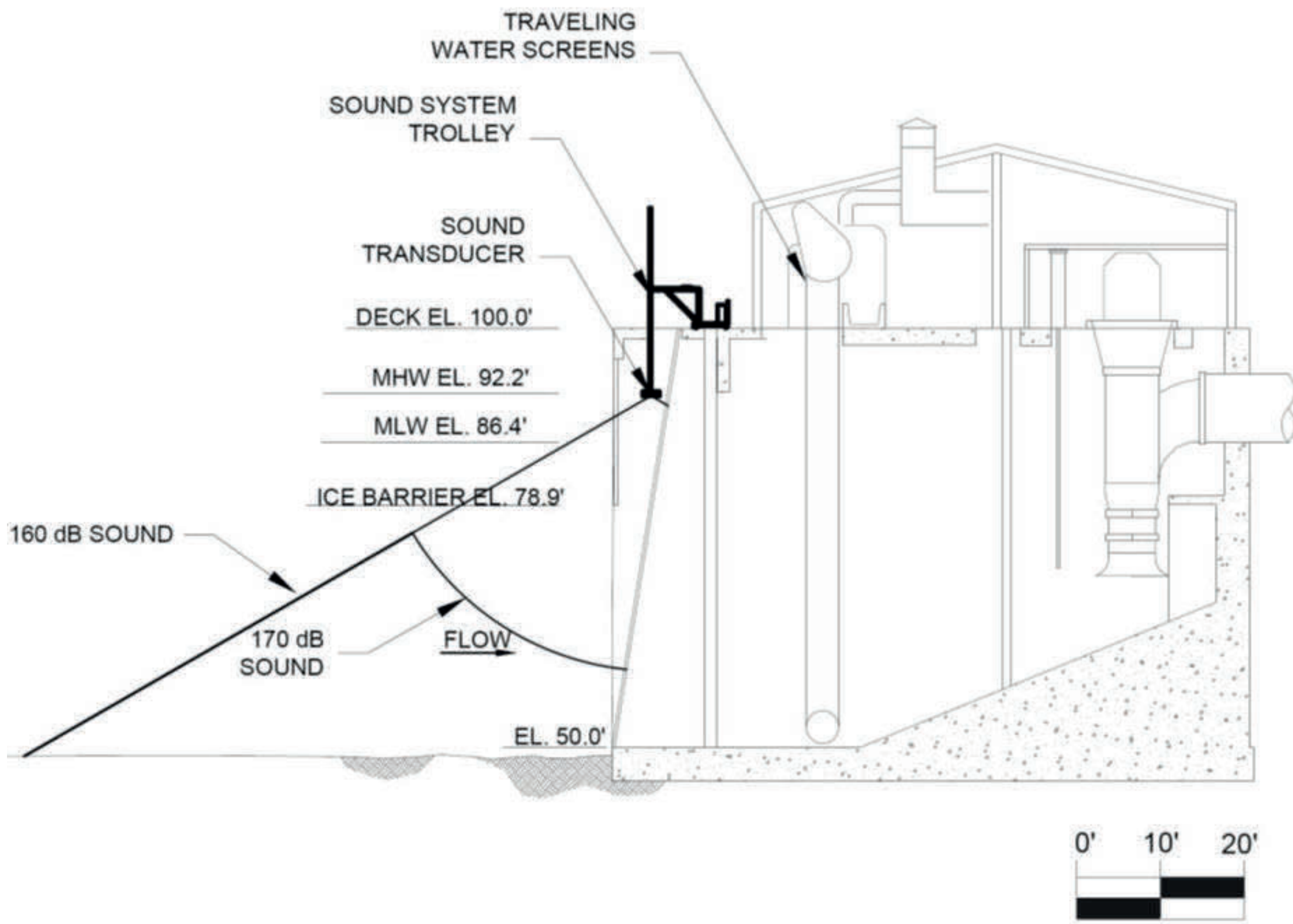

Figure 7-3. Conceptual Layout of a sound deterrent mounted to a mobile trolley – elevation view.

The sound systems would operate with a 50% duty cycle (i.e., sound signals would be emitted with a sequence of 0.5 second on and 0.5 seconds off). This duty cycle should provide a sufficient behavioral determent while limiting power consumption. However, this may need to be refined based on additional testing of sturgeon responses. Each sound transducer requires approximately 1,000 watts to operate. The peak power consumption and total annual power consumption for each alternative is provided in Table 7-1.

7.1.3 Operational Impacts

Operating a sound deterrent sysem would require power to be drawn from the existing station service. The energy demand for both sound options is shown in Table 7-1. When divers are working near the intake during the initial installation and sound mapping, SGS may need to reduce flow to reduce the velocity at the CWIS. The addition of either sound alternative is not expected to have any other operational impacts.

7.1.4 Expected Biological Effectiveness

There is only limited information describing sturgeon hearing and response to various frequencies and pressure thresholds, with the exception of the few studies conducted with Lake Sturgeon (Lovell et al. 2005; Meyer et al. 2010). In 2015, a commercial device referred to as a boomer set to produce a sound level of 204 dB re 1uPa peak at a repetition rate of 20/min was used to deter sturgeon from blasting in the Delaware River. Based on results of a pilot study, peak noise levels were not expected to exceed 193 dB 1 µPa at a distance of 5.3 m from the sound source. Although the sample size was small, sturgeon spent 50% less time in the blasting area when the sound was on compared to when it was off (ERC 2015). These observations indicate a sound deterrent could be a viable option for deterring sturgeon at SGS. However, due to the limited information on sturgeon hearing, including frequency detection and SPL thresholds, laboratory and/or field evaluations of sturgeon responses to a range of sound signals using conventional transducers and a boomer would provide valuable information and data for optimizing a sound deterrent system for deployment at SGS to reduce Atlantic Sturgeon incidental take.

Table 7-1. Additional Labor and Power needed to Operate and Maintain a Sound Barrier.

Alternative	Additional Labor (man hours)	Peak Power (kW)	Annual Power Required (kWh)
Intake Mounted Transducers	314	4	17,520[1]
Cart-mounted Transducer	104	2	1,251[2]

1. Assumed to be operated continuously throughout the year with a 50% duty cycle
2. Assumed to be operated three days per week for eight hours per day with a 50% duty cycle

7.1.5 Uncertainty and Risks

The ability of sound systems to effectively produce avoidance responses in sturgeon species has not been extensively investigated (particularly compared to some other fish species). Therefore, testing in the laboratory with multiple low frequencies prior to any field installation could provide insight into the specific sound signals and SPLs that would be most appropriate for sturgeon. Site-specific conditions (primarily bottom type and contours and project configuration) can affect the underwater propagation of sound. An acoustic model study should be conducted prior to completing the final design of any sound deterrent system to properly locate and orient the sound transducers so as to provide full coverage for each alternative. The sound pressure waves radiating out from the transducers over the range of frequencies expected to be effective at SGS would be modeled in this type of evaluation. The model results would provide a theoretical map of the sound field around the intake.

After installation of the sound barrier, a sound mapping field study should be conducted to verify the sound field of the deterrent system. This study would require the installation of hydrophones or a mobile survey conducted within the sound field. Field measurements would record both the frequency and magnitude of the sound at specified distances and depths at the intake and out into the Delaware River. Any background noise and sound attenuation occurring from the trash rake and ice barrier would also be detected. If the sound field does not match what is required to create an effective sound barrier, the sound transducers could be adjusted until the desired sound field is achieved. Costs for numeric model study and the field mapping and calibration study are included in the cost estimate for the installation of both sound barrier alternatives.

Additional testing in the lab and/or in the field to determine the most effective frequency to deter sturgeon and acoustic modeling to refine the system design would be helpful prior to deploying this TOM alternative. These could include cage studies to evaluate sturgeon behavior. Without these studies, it is difficult to assess the probability for effective application. However, it may be possible to deploy and evaluate a sound deterrent system in the near term without the information from these studies if there is acceptance of the uncertainties. With additional information from biological testing and acoustic modeling, a sound deterrent system may prove to be a long term solution that can be applied immediately with little risk if it does not prove effective.

7.2 Hanging Chains Mounted to the Trash Rake

7.2.1 Design and Construction

This TOM uses short hanging chains or cables (referred to as chains) that act as ticklers to startle sturgeon on or near the trash rack just prior to them encountering the trash rake. During periods of low debris loading when the rake can be fully deployed before closing, the hanging chains would be effective over the entire height of the rack. When there is debris on the rack the chains are intended to startle the sturgeon that may be present higher in the water column prior to closing of the rake. The buildup of debris within the rake may push the chains up, at which point the debris itself is expected to act as a tickler to the sturgeon below the rake.

Twisted stainless steel chain or cable is recommended for this TOM to reduce twisting as they interact with the trash rack and debris. These should be light weight or include a weak link that can be easily broken by the rake if the chains become entangled on the rack. The chains would most likely break and quickly fall to the bottom so there would be little to no chance of damage to the rake or traveling screens. The chains would be mounted to the six bars and outer tube steel across the top of each trash rake. The chains could either be welded into place or bolted through the bars. The chains would be up to 2 ft long and mounted in an alternating pattern (Figure 7-4). This arrangement was selected to limit the spacing between chains to approximately 8 inches on the same mounting bar and no more than an approximately 6 inch diagonal between chains on adjacent bars. The majority of sturgeon collected by the rake during debris removal at the SGS inatke are between about 20 and 30 inches (50 to 80 cm) in length with approximate girths between 7 and 11 inches. Therefore, the spacing arrangement of the chains will insure contact with sturgeon that the rake encounters. The chains would consist of multiple lengths, with the shorter lengths being closest to the gripper. The length and position of the chains should also reduce the chance of sturgeon getting hung up or caught on the trash rack, or interfering with the opening and closing of the rake.

7.2.2 Operation and Maintenance (O&M)

Once installed hanging chains would require limited O&M. They should be inspected at the start and end of cleaning the six trash rack bays per unit. Any damaged or missing chains should be replaced prior to the next cleaning cycle. The chains are designed to break free if entangled with the trash rack, to account for this 25% of the chains were assumed to need replacement annually. Overall, this is estimated to add approximately two hours to each cleaning cycle.

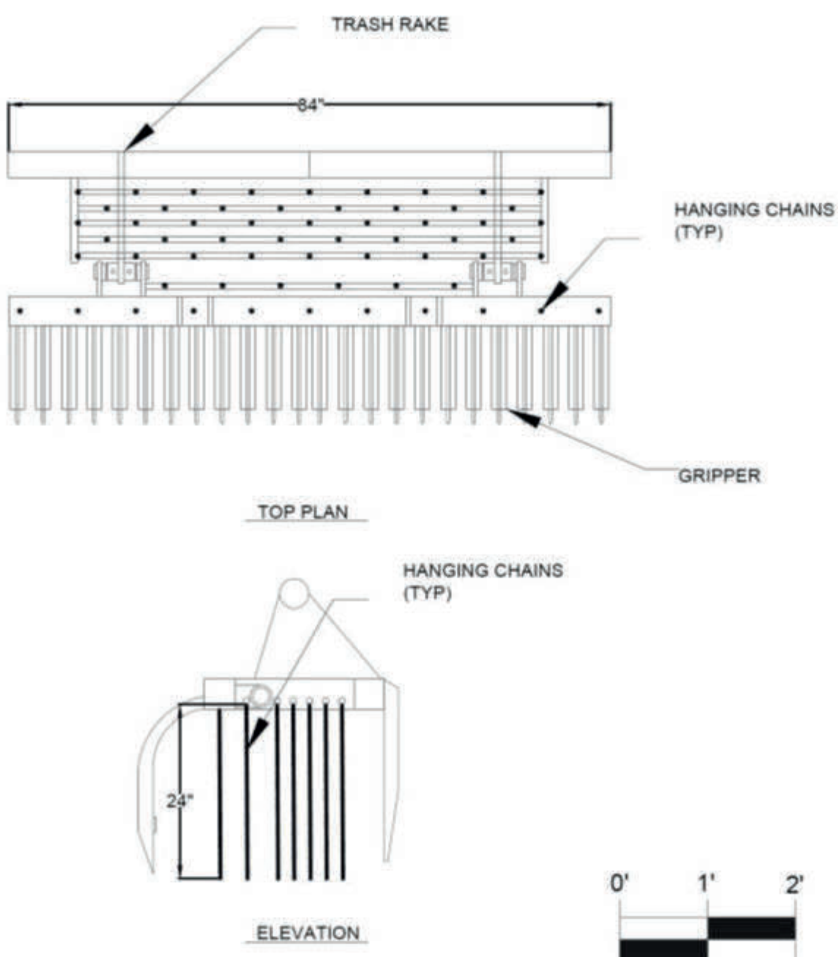

Figure 7-4. Conceptual layout of a trash rake mounted hanging chains – plan and elevation views.

7.2.3 Operational Impacts

This TOM is not expected to result in any operational issues; however PSEG maintenance and engineering personnel have expressed some serious reservations about broken pieces of chain becoming lodged in the trash bars or impacting on the traveling water screens.

7.2.4 Expected Biological Effectiveness

Hanging chains mounted to the trash rake could potentially startle and repel sturgeon away from the rake. The chains would not act as a sound deterrent, but would be used as a tickler to scare fish away as the rake moves down the rack. There are some studies that indicate hanging chains can be effective at starling fish. However, no studies have investigated the effectiveness of this technology with sturgeon species. The majority of the research with hanging chains was conducted in the 1950s with salmon. During a laboratory study, a hanging chain positioned at 45° to the flow was tested as a method to guide yearling Sockeye Salmon with 71% of fish deflected at night (Brett et al. 1954). Another study by Fields et al. (1955) investigated hanging chain curtains for use with Steelhead Trout (*Oncorhynchus mykiss*) and Chinook (*O. tshawytscha*) and Coho (*O. kisutch*) Salmon. In this study, about 46% of fish were either blocked or guided by the chains. A field study conducted at the Puntledge Hydropower Generating Station in British Columbia tested a hanging chain curtain in combination with a hammer and strobe lights as a deterrent for Coho Salmon smolts. The results of this study indicated there was no significant difference in the number of smolts entrained with the behavioral devices on or when they were off (Bengeyfield and Smith 1989).

Although the results of studies that have investigated hanging chains for fish guidance or deterrence have been variable, tickler chains have been used with trawl nets to scare fish off of the bottom and into the nets. Addition of tickler chains to trawls increased catches for multiple fish species (Kaiser et al. 1994; Reid et al. 2012). This type of application indicates chains can be effective in startling fish and, therefore, could be used to scare sturgeon away from the SGS trash rack during raking operations.

7.2.5 Uncertainty and Risks

Despite previous research as a fish deterrent and guidance device, as well as a tickler for bottom trawls, there is no available information or data that would indicate how hanging chains may perform as fish deterrent when mounted on the trash rake at SGS. However, adding hanging chains to the rake is a relatively inexpensive alternative that may warrant testing and monitoring in the field to determine effectiveness.

The placement of the chains on the rake is designed to reduce the potential for hang-ups or snags on the trash rack. However, the chain will quickly corrode and there is still a possibility for the chains to become snagged or ripped off. This could require frequent replacement of the chains or cause damage to the rake. Broken chains would most likely be entwined within the debris or quickly fall to the bottom but there is some potential for pieces of chain to become lodged in the trash bars or impact on the traveling screens.

7.3 More Frequent Cleaning of the Rack with Delayed Closing of the Rake

7.3.1 Design and Construction

Standard operating procedures for the trash rack already includes several measures to reduce sturgeon take. These include:

- Cleaning the CWIS trash bars at least once per week;
- Inspecting the CWIS trash bars at least once per 12-hour shift;
- Lowering the rake with the gripper in the closed, semi-closed or open position until it reaches the intake base;
- Leaving the gripper in the semi-open position in order to allow for fish escape while the rake is underwater.

These existing operational measures have not resulted in less incidental take of Atlantic Sturgeon and may reduce the cleaning efficacy of the rake. This TOM alternative is designed to build on the existing operational measures to provide greater opportunity for sturgeon to move away from the trash rack and rake during cleaning operations. This will be achieved through a combination of four different operational changes:

- Increased cleaning frequency to twice per week
- Slowing of the rake descent speed
- Increase in the delay between lowering the rake and closing it
- Increase delay before starting the next cleaning cycle

Currently, cleaning of the trash rack is undertaken when operators see a water level difference of approximately 12 inches across the trash rack. Through-rack velocities along with the estimated head loss for different debris loading conditions at the mean low water levels are provided in Table 7-2. At a 6-inch differential the trash rack is approximately 76% plugged and with a 12-inch differential it is approximately 83% plugged.

Increasing the cleaning frequency would increase the effective area for water to pass through the trash rack. This would improve the flow distribution across the trash racks and reduce eddies and high velocity zones that have potential to impinge or entrap sturgeon or limit their ability to avoid capture by the rake during debris removal. The larger effective surface would also reduce the overall approach and through-rack velocities, reducing the level of effort necessary for sturgeon to swim away from the rack and rake. A cleaner rack would also reduce the pressure holding debris and the trash rake to the rack, increasing the cleaning efficiency of the trash rake.

Slowing the rake descent speed would give sturgeon more opportunity to escape the rake and prevent sturgeon from becoming impinged on the top plate of the trash rake as it moved down the trash rack. A slower rake speed may reduce the ability of the rake to push debris down the rack. Adding weight to the trash rake may offset any reductions in cleaning efficiency associated with reducing the lowering speed. Once sturgeon have dispersed from the active cleaning area the speed of the rake could be increased in subsequent passes to further overcome any cleaning inefficiencies. Slowing the descent speed of the rake is expected to have less of an impact on cleaning efficiency than the current procedure of lowering the rake closed or semi-closed.

Table 7-2. Estimated velocity and head loss through the trash rack for different debris loading conditions at the mean low water level.

Trash Rack Blockage (%)	Estimated Through Rack Velocity (ft/sec)	Estimated Head Loss through the Trash Rack at (inches)
0%	1.19	0.1
10%	1.32	0.2
20%	1.48	0.3
30%	1.69	0.5
40%	1.98	0.8
50%	2.37	1.3
60%	2.96	2.1
70%	3.95	3.9
76%	4.84	6.0
80%	5.93	9.1
83%	6.78	12.0
90%	11.86	37.2

Delaying the closing of the rake at the end of its down stroke would provide sturgeon that interact with the rake a greater opportunity to escape before being collected with the debris. Pairing this operational change with maintaining a cleaner rack would reduce the likelihood of sturgeon becoming entangled within the debris and prevent them from escaping. Holding the rake open for approximately one minute at the end of the downs stroke should be sufficient to allow sturgeon to escape the rake. Additionally, it is thought that increased localized suction towards and through the trash racks after debris is removed by the rake may be trapping or disorienting sturgeon near the rack. Increasing the delay between the cleaning cycles could allow sturgeon to recover and swim away from high velocity suction zones.

This TOM alternative represents a combination of operational measures and does not require any changes to the design of the trash rack or rake.

7.3.2 Operation and Maintenance (O&M)

These operational changes will increase both the number and duration of trash rack cleanings. Increasing the effective area of the rack will reduce velocities at the rack which in turn would reduce the pressure holding debris against the rack. These benefits combined with less debris buildup should increase the overall cleaning efficiency of the trash rack allowing the entire rack to be cleaned with fewer passes.

Modifications to rake operations and maintaining the rack in a clean condition was assumed to require a threefold increase in effort over current operations.

7.3.3 Operational Impacts

Implementation of this alternative is expected to result in a minor increase in station power use and an increase in labor hours necessary to maintain the rack and the trash rake. The increase frequency for cleaning would only be necessary during peak sturgeon seasons.

7.3.4 Expected Biological Effectiveness

Once the rack is cleaned thoroughly and remains clean, the velocities at the rack are expected to be much lower. Reduced velocities will create a more suitable environment that sturgeon can easily navigate, thus allowing them to swim away from the trash rack rather than being impinged or captured by the rake. Juvenile sturgeon critical and maximum sustained swim speeds range from 0.5 to 5.6 ft/sec depending on the species and length (refer to Table 2-1 in Section 2). Therefore, ensuring velocities remain both uniform and below the critical swim speeds could lead to less sturgeon impingement and rake capture. In addition to the lower velocities, delaying the rake closing would also allow sturgeon time to swim away from the rack before being subject to capture by the rake.

7.3.5 Uncertainty and Risks

The effects of these operational measures on the behavior of sturgeon and their ability to escape from the trash rake are unknown. Higher flow velocities at the rack are assumed based on debris accumulation and have not been measured. If sturgeon are capable of negotiating the existing hydraulic conditions at the rack and these conditions are not the cause for the increase in sturgeon take, changing the cleaning frequency may not lead to a reduction in incidental take.

The three operational measures identified for this TOM alternative are compatible with existing equipment and could be applied immediately. There is a risk that these measures would not be effective, but the risk of potentially increasing take is low.

7.4 Modified Ice Barrier Installation and Removal Schedule

7.4.1 Design and Construction

The take of surgeon at SGS correlates to the period when the ice barrier is installed as shown in Figure 3-1 in Section 3. In addition to the known movement patterns of Atlantic Sturgeon in this region of the Delaware River where SGS is located, increased take during the period when the ice barrier is in place may be due, in part, to unfavorable hydraulic conditions at the rack and under the ice barrier that leads to the entrapment of sturgeon in the upper section of the intake bays. This may result in sturgeon being susceptible to rake capture because the hydraulic conditions with the ice barrier installed and considerable debris loading on the lower portion of the trash rack limit the ability of sturgeon to escape the rake. The goal of this TOM is to reduce or eliminate unfavorable hydraulic conditions by reducing or eliminating the period when the ice barrier is deployed and thereby providing sturgeon with increased ability to escape the intake during debris removal. This TOM should also be paired with the previous TOM to maintain a clean trash rack when the ice barrier is installed.

The ice barrier is intended to prevent large sheets of pack ice from entering the CWIS, where it can accumulate and eventually plug the trash rack. When installed, the ice barrier extends down to elevation 78.9 ft, which is 7.5 ft below the mean low water level. The bottom of the ice barrier is approximately 4 ft in front of the trash rack. The ice barrier is constructed with wooden planks spaced several inches apart, which is slightly narrower than the trash rack bar spacing. These openings allow flow to pass through the ice barrier when clean. Debris that accumulates against the ice barriers is generally removed by the reversing tide, but debris buildup on the ice barrier is expected to plug these openings at a similar rate as the trash rack.

As the lower portion of the trash rack and ice barrier plug, flow through the trash rack is concentrated through the upper portion of the rack that is screened by the ice barrier. This creates significant turbulence and an upwelling through the narrow gap between the trash rack and ice barrier. This turbulence and the upwelling is demonstrated in the Figure 7-5 photograph. Estimated velocities through this gap with different amounts of debris loading on the trash rack and ice barrier are provided in Table 7-3. With head losses of 6 inches and 12 inches across the trash rack, the velocity through the gap would be as high as approximately 4.5 ft/sec to 5 ft/sec, respectively. The velocity through the gap would be oriented near vertically, making it difficult for sturgeon to swim against. These velocity conditions likely contribute to sturgeon becoming trapped and disoriented in the upper portion of the trash rack bay, making them susceptible to impingement and collection by the trash rake.

Ice in the Delaware River and Estuary has been declining and will most likely continue to decline in the future due to continued warming temperatures (PDE 2017). Significant ice events have been rare in recent years, so the ice barrier may not need to be installed at all or only for a limited amount of time. Discontinuing use of the ice barrier or reducing the time period of deployment would eliminate or reduce the vertical currents at the trash rack and the potential for sturgeon to become entrapped between the ice barrier and trash rack. Without the ice barrier in place sturgeon would be more likely to swim away from the trash racks rather than be impinged or caught by the trash rake. Alden therefore recommends minimizing or eliminating the use of the ice barrier.

Figure 7-5. Flow conditions in a trash rack bay with the ice barrier installed after rack cleaning.

Table 7-3. Velocity through the gap between the trash rack and ice barrier.

Trash Rack and Ice Barrier Plugging (%)	Flow Through the Gap Between the Ice Barrier and Trash Rack (cfs)	Calculated Velocity through the Gap (ft/sec)
0%	0.0	0.0
10%	41.2	0.6
20%	82.4	1.2
30%	123.7	1.8
40%	164.9	2.4
50%	206.1	2.9
60%	247.3	3.5
70%	288.5	4.1
80%	329.7	4.7
90%	371.0	5.3
100%	412.2	5.9

7.4.2 Operation and Maintenance (O&M)

Ice reports for the lower basin of the Delaware River from the National Weather Service should be monitored to help with long-term forecasting to predict ice packs in the vicinity of the SGS intake. The trash rack should be fully cleaned and maintained in a clean condition prior to installation of the ice barrier. A clean trash rack will limit the upwelling of flow in front of the trash rack.

7.4.3 Operational Impacts

Without the ice barrier installed, the SGS CWIS could be subject to pack ice issues. Large ice events have not occurred in recent years and are expected to occur with even less frequency as a result of climate change. Analyzing the long-term data to better define the period of concern should reduce the potential for pack ice related operational issues.

7.4.4 Biological Effectiveness

As previously discussed, the ice barrier may contribute to increased turbulence and high velocities between the barrier and the trash rack that sturgeon are unable to negotiate, resulting in impingement or capture by the trash rake. Currently, the ice barrier is installed for almost seven months each year (fall through spring) during periods when sturgeon abundance in the vicinity of SGS are expected to be seasonally high. Removal of the ice barrier would reduce the turbulence and high velocities that may be causing issues for sturgeon and subsequent capture by the rake. Juvenile sturgeon critical and maximum sustained swim speeds have been shown to range from about 0.5 to 5.6 ft/sec. Reducing turbulence and reducing flow velocities to levels below the critical swim speeds of juvenile fish should allow sturgeon to swim away from the trash racks and reduce trash rake capture.

7.4.5 Uncertainty and Risks

Flow conditions and velocities resulting from the installation of the ice barrier, debris build up on the barrier, and debris build up on the lower portion of the racks have not been measured. Consequently, there is some uncertainty as to how these conditions may actually be impacting the hydraulic fields between the barrier and the racks. If sturgeon are capable of swimming against the velocities at the rack and through the gap between the ice barrier and trash rack under current flow conditions, reducing the period of ice barrier deployment and reducing debris loading on the trash rack may not lead to reduced incidental take of sturgeon.

This TOM does not require any new equipment and could be implemented immediately. There is a risk that it may not prove to be effective at reducing sturgeon take.

7.5 Hydroacoustic Monitoring of the Intake and Trash Rack to Assess TOM effectiveness and to Determine Presence/Absence of Sturgeon Prior to Initiating Raking Operations

7.5.1 Design and Construction

A hydroacoustic monitoring system would be used to determine the presence and behavior of sturgeon prior to initiating debris removal operations and would allow PSEG to estimate the effectiveness of the previously described TOMs. For SGS, a hydroacoustic monitoring system would use an ARIS acoustic camera that would be mounted on a 30-ft extendable pole. A second ARIS could also be rented or purchased allowing the use of two at the same time (i.e., increased intake coverage) and to have a backup if one were to fail or needed to be serviced.

The ARIS units could be mounted to a similar or the same trolley system as designed for a mobile sound deterrent system. However, if the ARIS is mounted on the same cart as the sound system it would preclude the ability to monitor for sturgeon when the mobile sound system is operating (i.e., both and ARIS and a sound transducer could not be deployed at the same time). Alternatively, a separate trolley system with telescopic arm could be used for an ARIS camera. The mounting system would allow the units to be raised and lowered into the water and angled to survey the entire rack (Figure 7-6).

Figure 7-6. ARIS sonar unit with tilt mount (image from soundmetics.com).

7.5.2 Operation and Maintenance

The ARIS could be used at any time to monitor the trash rack for cleaning purposes. The frequency of these trash rack checks may depend on the season and the amount of debris in the area. During the sturgeon season, the ARIS could be used before or during each raking session to determine presence of sturgeon. The ARIS units should be inspected and cleaned regularly. The ARIS units should be inspected prior to each operation of the trash rake and these inspections can be conducted on deck. Cleaning the units should be conducted no less than monthly.

7.5.3 Operational Impacts

A second operator and additional support labor would be needed to operate the ARIS before and during cleaning operations if it is plausible to operate simultaneously as the rake. Operation of the ARIS camera is expected to result in a minor increase in station power use.

7.5.4 Expected Biological Effectiveness

ARIS acoustic cameras have been used to effectively monitor fish in variety of environments during laboratory and field studies. The advantage of the ARIS technology (as with any hydroacoustic technology) is the ability to detect images under low or no light conditions and in high turbidity environments. ARIS cameras are capable of distinguishing targets up to 35 m away and provide a well-defined image that would allow for sturgeon to be readily identified in most instances, although this can be variable depending on the environment. For the purposes of this application, resolution would only be needed for up to 5m. Hydroacoustic monitoring with a system like the ARIS would allow PSEG to determine trash bar cleanliness and condition. Dependent on deployment logistics, it may be feasible to monitor for sturgeon presence prior to or during raking. Once presence is known, raking operations could be delayed or a deterrent measure (e.g., sound) could be used to repel fish prior to rake operation. The use of monitoring equipment would also allow PSEG to assess the effectiveness of any TOM that is implemented.

7.5.5 Uncertainty and Risks

ARIS units are relatively expensive and may require maintenance and/or replacement (if damaged) every few years. These units could provide valuable information during the initial deployment of the other TOMs, but may not be needed in subsequent years if one of the TOMs is proven effective and monitoring is no longer needed. The simultaneous use of the ARIS alongside the trash rake may not be plausible due to complications with multiple moving parts such as skids and cables. Instead, the ARIS may need to be used prior to any raking. A seasonal rental of a unit or two may be a more cost effective alternative than purchase. Additional pilot testing of hydroacoustic unit deployment from the intake deck is recommended to determine the most effective deployment techniques and to refine the logistics. Alternatively, there may be less expensive options such as commercially available fish finders that would be capable of determining the presence and absence of large fish at SGS. The downside of fish finder units is that they would not provide the same level of detail for the identification of sturgeon or on the movement of sturgeon at the intake.

8.0 Cost Estimates for Selected TOMs

A qualitative assessment of costs was developed for each of the five TOMs carried forward to the detailed feasibility analysis. The costs were estimated using best professional judgement of the material and labor costs to construct and maintain the TOMs. In some cases technology-specific costs based on manufacturer input for SGS, along with estimates for other projects that were adjusted for identifiable differences in project sizes and operations were used to estimate an approximate cost range. These costs allow a valid comparison of the cost difference among alternatives. The anticipated construction and O&M costs for each TOM are presented in Table 8-1.

Table 8-1. Cost comparison of evaluated TOMs.

TOM	Total Project Construction Costs	Annual O&M Costs
Sound Deterrent Installed at the Face of the Intake	$$$$	$$$
Sound Deterrent Mounted to the Trash Rake Trolley	$$$	$$
Hanging Chains Mounted to the Trash Rake	$$	$$
More Frequent Cleaning of the Rack with Modified Rake Speed and Delayed Closing of the Rake	$	$$$
Modified Ice Barrier Installation and Removal Schedule	$	$
Hydroacoustic Monitoring of the Intake and Trash Rack	$$$	$$

$$$$= >$1,000,000
$$$= $100,000 through $1,000,000
$$ = $10,000 through $1,000,000
$= $0 through $10,000

9.0 Summary and Recommendations

The evaluation of TOMs for reducing incidental take of sturgeon (primarily Atlantic Sturgeon) at the SGS cooling water intake included an extensive and stepwise review of available fish protection technologies and potential operational modifications. Most technologies and operational modifications that were identified and evaluated have not been investigated or installed for sturgeon, or for reducing fish collection during debris removal operations at intake trash racks. Also, many of the alternatives evaluated or applied to protect sturgeon were for downstream passage purposes and the reduction of turbine entrainment at hydro turbine intakes. Because the conditions leading to sturgeon take at the SGS intake are unique and not a fish entrainment issue (and possibly not an impingement issue either), conventional physical exclusion technologies (e.g., various types of screens, narrow-spaced bar racks, diversion and guidance structures) are not applicable. Consequently, the results of the feasibility assessment and screening of alternatives for reducing sturgeon take led to the selection of five alternatives that included a behavioral deterrent (sound) and several operational modifications focused on improving debris removal operations and maintenance of a clean trash rack. However, there is insufficient experience and knowledge to definitively conclude that any of the five recommended alternatives, applied either alone or in combination, will reduce incidental take of sturgeon. Rather, the feasibility assessment presented in this report demonstrates that the selected alternatives have some level of potential for reducing take based on currently available information for each approach (i.e., experience, design, and/or biological performance), a thorough understanding of the design and operation of the SGS intake, and the professional knowledge and experience of Alden’s engineers and fisheries scientists with respect to the protection of fish at water intakes.

Implementation of any of the five selected TOMs, alone or combined, will require monitoring and/or pilot testing to determine effectiveness at reducing sturgeon take. Because none of the selected alternatives appears to have a major advantage over others and all of them can be implemented in a relatively short time frame, particularly the operational modifications, an adaptive management and testing approach can be employed through iterative application of the alternatives and effectiveness monitoring. Use of a sound deterrent system may be the only approach that could require some level of pilot testing in order to determine the most effective sound signal characteristics for repelling sturgeon and strength of avoidance responses under field conditions at the intake. Reducing the period of the ice barrier deployment (i.e., later installation and earlier removal) combined with increased debris removal operations (with a goal of maintaining a clean trash rack over the full depth) can be implemented initially, along with changes in the operation of the trash rake designed to reduce sturgeon capture and increased escapement. In conjunction with the implementation of these operational measures, hydroacoustic monitoring can be used to assess debris removal effectiveness and for the presence of sturgeon at the intake. A sound deterrent system can be installed and tested on a pilot-scale if it is determined that operational measures alone will not reduce sturgeon take to required levels. Prior to field deployment, it would be helpful, if possible to investigate sturgeon responses to a range of sound signal characteristics (i.e., frequency, signal type, pulse widths, duty cycle, sound pressure levels, etc.) through cage or laboratory testing to optimize the sound deterrent for avoidance. Regardless of the measures implemented, multiple years of testing and monitoring will likely be required to account for environmental and population effects that may contribute to fluctuations in annual take numbers.

10.0 References

Adams, S.R., J.J. Hoover, K.J. Killgore. 1999. Swimming endurance of juvenile pallid sturgeon, *Scaphirhynchus albus*. Copeia. 1999 (3): 802-807.

Adams, S.R., G.L. Adams, G.R. Parsons. 2003. Critical swimming speed and behavior of juvenile shovelnose sturgeon and pallid sturgeon. Transactions of the American Fisheries Society. 132: 392-397.

ARL (Alden Research Laboratory, Inc). 2004. Evaluation of New Water Screening Technologies for Improved Debris Management and Fish Protection at the Salem Nuclear Generating Station. Prepared for Public Service Electric and Gas Company (PSEG).

ARL (Alden Research Laboratory, Inc). 2005. Phase 2 Report: Custom requirement G.5 Multi-sensory hybrid intake protection technology feasibility study section 316(b) special condition. Prepared for PSEG Nuclear, LLC.

ARL (Alden Research Laboratory, Inc). 2009. Evaluation of Downstream Passage Efficiency of Shortnose Sturgeon. Prepared for the City of Holyoke, Massachusetts.

ARL (Alden Research Laboratory, Inc). 2010. Evaluation of Downstream Passage Alternatives for Shortnose Sturgeon. Prepared for the City of Holyoke, Massachusetts.

Amaral, S. V., J. L. Black, B. J. McMahon, and D. A. Dixon. 2002. Evaluation of Angled Bar Racks and Louvers for Guiding Lake and Shortnose Sturgeon. Pages 197-210 *in* W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, Management, and Protection of North American Sturgeon. American Fisheries Society, Symposium 28, Bethesda, Maryland.

Bengeyfield, W., H.A. Smith. 1989. Evaluation of behavioral devices to divert Coho Salmon from the penstock intake at Puntledge Generating Station. Prepared for B.C. Hydro Environmental Resources.

Bouyoucos, I., P. Bushnell, R. Brill. 2013. Potential for electropositive metal to reduce the interactions of Atlantic Sturgeon with fishing gear. Conservation Biology. 00: 1-5.

Boysen, K.A., J.J. Hoover. 2009. Swimming performance of juvenile white sturgeon (*Acipenser transmontanus*): training and the probability of entrainment due to dredging. Journal of Applied Ichthyology. 25: 54-59.

Breece, M.W., M.J. Oliver, M.A. Climino, D.A. Fox. 2013. Shifting distributions of adult Atlantic sturgeon amidst post-industrialization and future impacts in the Delaware River: a maximum entropy approach. Plos One. 8(11):1-13.

Brett, J.R., D. MacKinnon, and D.F. Alderdice. 1954. Trough experiments on guiding sockeye salmon fingerlings. Progress Reports of the Pacific Coast Stations of the Fisheries Research Board of Canada 99:24-27.

Brundage, H.M., R.E. Meadows. 1982. The Atlantic sturgeon*, Acipenser oxyhynchus*, in the Delaware River estuary. Fishery Bulletin. 80 (2): 337-344.

Brundage, H.M. J.C. O'Herron. 2009. Investigations of juvenile shortnose and Atlantic sturgeon in the lower tidal Delaware River. Bulletin: New Jersey Academy of Science. 54 (2): 1-8.

Coutant, C.C. 2001. Turbulent Attraction Flows for Guiding Juvenile Salmonids at Dams. Pages 57–77 in C. Coutant, editor. Behavioral Technologies for Fish Guidance. American Fisheries Society, Symposium 26, Bethesda, MD.

Dennis, C.E. 2019. Evaluating the ability of sound, an air curtain, and high-intensity light, both alone and together, to deter bighead and common carps. Thesis for University of Minnesota. pp 174.

Deslauriers, D., J.D. Kieffer. 2012. Swimming performance and behavior of young-of-the-year shortnose sturgeon (*Acipenser brevirostrum*) under fixed and increased velocity swimming tests. Canadian Journal of Zoology. 90: 345-351.

Donaldson, M.R., J. Amberg, S. Adhikari, A. Cupp, N. Jensen, J. Romine, A. Wright, M. Gaikowski, C.D. Suski. 2016. Carbon dioxide as a tool to deter the movement of invasive Bighead Carps. *Transactions of the American Fisheries Society*. 145(3): 657-670.

Dovel, W.L., T.J. Berggren. 1983. Atlantic sturgeon of the Hudson estuary, New York. New York Fish and Game Journal. 30(2): 140-172.

Elvidge, C.K., C.H. Reid, M.I. Ford, M. Sills, P.H. Patrick, D. Gibson, S. Backhouse, S.J. Cooke. 2019. Ontogeny of light avoidance in juvenile lake sturgeon. Journal of Applied Ichthyology. 35: 202-209.

PSEG. 2019. Review and Screening of Technologies for Entrainment Reduction. Prepared for AKRF, Inc and Public Service Electric and Gas Company (PSEG). October 2019

EPRI (Electric Power Research Institute). 2000. Evaluation of angled bar racks and louvers for guiding fish at hydroelectric projects. Prepared by Alden Research Laboratory, Inc., EPRI Report No. EPRI TR-1005193.

EPRI (Electric Power Research Institute). 2006a. Evaluation of an angled louver facility for guiding sturgeon to a downstream bypass. Prepared by Kleinschmidt Associates, Inc. Report No. EPRI-1011786.

EPRI (Electric Power Research Institute). 2006b. Field Evaluation of Wedgewire Screens for Protecting Early Lifestages of Fish at Cooling Water Intakes: Chesapeake Bay Studies. Prepared by Alden Research Laboratory. 1012542.

ERC (Environmental Research and Consulting, Inc.). 2015. Report of a study to determine the feasibility of using underwater sound to behaviorally exclude sturgeons from the blasting area for the Delaware River Main Channel Deepening Project. Environmental Research and Consulting, Inc., Kennett Square, PA.

Fields, P.E., G.L. Finger, R.J. Adkins, R.E. Carney, and R. Pyke. 1955. A factorial study of the response of steelhead trout, chinook and silver salmon fingerlings to chain barriers in moving water, Technical Report No. 13. School of Fisheries, University of Washington, Seattle, Washington.

Ford, M.I., C.K. Elvidge, D. Baker, T.C. Pratt, K.E. Smokorowski, P. Patrick, M. Sills, S.J. Cooke. 2017. Evaluating a light-louver system for behavioural guidance of age-0 White Sturgeon. River Research and Application. 33: 1286-1294.

Ford, M.I., C.K. Elvidge, D. Baker, T.C. Pratt, K. E. Smokorowski, M. Sills, P. Patrick, S.J. Cooke. 2018. Preferences of age-0 White Sturgeon for different colours and strobe rates of LED lights may inform behavioural guidance strategies. Environmental Biology of Fishes. 101: 667-674.

Gelwicks, K. R., D. J. Zafft, and J. P. Bobbitt. 1998. Efficacy of carbonic acid as an anesthetic for Rainbow Trout. North American Journal of Fisheries Management 18:432–438.

Hale, E.A., I.A. Park, M.T. Fisher, R.A. Wong, M.J. Stangl, J.H. Clark. 2016. Abundance estimate for and habitat use by early juvenile Atlantic sturgeon within the Delaware River Estuary. 145: 1193-1201.

Halvorsen, M.B., B.M. Casper, F. Matthews, T.J. Carlson, A.N. Popper. 2012. Effects of exposure to pile-driving sounds on the Lake Sturgeon, Nile Tilapia, and Hogchocker. Proceedings of the Royal Society. 279: 4705-4714.

Hoover, J.J., J. Collins, K.A. Boysen, A.W. Katzenmeyer, K.J. Killgore. 2011. Critical swimming speeds of adult shovelnose sturgeon in rectilinear and boundary-layer flow. Journal of Applied Ichthyology. 27: 226-230.

Hudson Engineering and ERC. 2020. Pilot study summary at Salem Generating Station circulating water system intake unit 1 and unit 2. Prepared for PSEG.

Kaiser, M.J., S.I. Rogers. D.T. McCandless. 1994. Improving quantitative surveys of epibenthic communities using a modified 2 m beam trawl. Marine Ecology Progress Series. 106: 131-138.

Kates, D., C. Dennis, M. R. Noatch, and C. D. Suski. 2012. Responses of native and invasive fishes to carbon dioxide: potential for a nonphysical barrier to fish dispersal. Canadian Journal of Fisheries and Aquatic Sciences 69:1748–1759.

Katopodis, C., R. Gervais. 2016. Fish swimming performance database and analyses. Canadian Science Advisory Secretariat. Research Document. 2016/002. Pp. 550.

Krebs, J., F. Jacobs, A.N. Popper. 2016. Chapter 67: Avoidance of pile-driving noise by Hudson River sturgeon during construction of the new NY bridge at Tappen Zee. In: The Effects of noise on aquatic life II. Advances in experimental medicine and biology. New York, NY. 555-564pp.

Kynard, B., M. Horgan. 2001. Guidance of yearling shortnose and pallid sturgeon using vertical bar rack and louver arrays. North American Journal of Fisheries Management. 21: 561-570.

Kynard, B., D. Pugh, and T. Parker. 2005. Experimental Studies to Develop Guidance and a Bypass for Shortnose Sturgeon at Holyoke Dam. Prepared for the City of Holyoke, Massachusetts.

Kynard, B., D. Pugh, and T. Parker. 2006. Experimental Studies to Develop Guidance and a Bypass for Shortnose Sturgeon at Holyoke Dam. Prepared for the City of Holyoke, Massachusetts.

Lovell, J.M., M.M. Findlay, R.M. Moate, J.R. Nedwell, M.A. Pegg. 2005. The inner ear morphology and hearing abilities of the Paddlefish (*Polyodon spathula*) and the Lake Sturgeon (*Acipenser fulvescens*). Comparative Biochemistry and Physiology, Part A: 286-296.

Meyer, M., R.R. Fay, A.N. Popper. 2010. Frequency tuning and intensity coding of sound in the auditory periphery of the Lake Sturgeon, *Acipenser fulvescens*. The Journal of Experimental Biology. 213: 1567-1578.

Michaud, D. T. and E. P. Taft. 1999. Recent Evaluation of Physical and Behavioral Barriers for reducing Fish Entrainment at Hydroelectric Projects in the Upper Midwest," Proceedings of the EPRI/DOE Power Generation Impacts on Aquatic Resources Conference, Atlanta, GA (April 1999).

Munday, P. L., D. L. Dixson, J. M. Donelson, G. P. Jones, M. S. Pratchett, G. V. Devitsina, and K. B. Døving. 2009. Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. Proceedings of the National Academy of Sciences of the United States of America 106:1848–1852.

NMFS (National Marine Fisheries Service). 2014. Endangered species action section 7 consultation biological opinion: Continued operation of Salem and Hope Creek Nuclear Generating Station. NER-2010-6581. 246pp.

NMFS (National Marine Fisheries Service). 2017. Endangered and Threatened Species; Designation of Critical Habitat for the Endangered New York Bight, Chesapeake Bay, Carolina and South Atlantic Distinct Population Segments of Atlantic Sturgeon and the Threatened Gulf of Maine Distinct Population Segment of Atlantic Sturgeon. Rule 82 FR 39160. 115 pp.

NMFS (National Marine Fisheries Service). 2018. National Marine Fisheries Service Endangered Species Act Biological Opinion: Deeping and Maintenance of the Delaware River Federal Navigational Channel. NER-2018-15005. 391pp.

NRC (Nuclear Regulatory Commission). 2020. Biological assessment of impacts to Atlantic Sturgeon and its critical habitat: Salem Nuclear Generating Station, Units Nos. 1 and 2. Docket #. 50-272, 50-311. 48pp.

PDE (Partnership for the Delaware Estuary). 2017. Technical report for the Delaware Estuary and basin 2017. PDE Report No. 17-07. 379pp.

Peake, S., F.W.H. Beamish, R.S. McKinley, D.A. Scruton, C. Katopodis. 1997. Relating swimming performance of lake sturgeon, *Acipensor fulvescens*, to fishway design. Canadian Journal of Fisheries and Aquatic Sciences. 54: 1361-1366.

Poletto, J.B., D.E. Cocherell, N.Ho, J.J. Cech, A.P. Kimley, N.A. Fangue. 2014a. Juvenile green sturgeon (*Acipenser medirostris*) and white sturgeon (*Acipenser transmontanus*) behavior near water-diversion fish screens: experiments in a laboratory flume. Canadian Journal of Fisheries and Aquatic Sciences. 71(7): 1030-1038.

Poletto, J.B., D.E. Cocherell, T.D. Mussen, A. Ercan, H. Bandeh. M.L. Kavvas, J.J. Cech Jr., N.A. Fangue. 2014b. Efficacy of a sensory deterrent and pipe modifications in decreasing entrainment of juvenile green sturgeon (*Acipenser medirostris*) at unscreened water diversions. Conservation Physiology. 2: 1-12.

Popper, A.N. 2005. A review of hearing by sturgeon and lamprey. Report by Environmental Bioacoustics. submitted to U.S. Army Corps of Engineers. Pp 24.

Popper, A.N., A.D. Hawkins, R.R. Fay, D.A. Mann, S. Bartol, T.J. Carlson, S. Coombs, W.T. Ellison, R.L. Gentry, M.B. Halvorsen, S. Lokkeborg, P.H. Rogers, B.L. Southall, D.G. Zeddies, W.N. Tavolga. 2014. Sound Exposure Guidelines for Fishes and Sea Turtles: A technical report prepared bt ANSI-Accredited standards committee S3/SC1 and registered with ANSI. Springer, London.

PSE&G (Public Service Gas & Electric Company). 1993. PSE&G Permit Renewal Application Salem Generating Station. Permit No. NJ0005622. 1993.

PSE&G (Public Service Gas & Electric Company). 1999. PSE&G Permit Renewal Application Salem Generating Station. Permit No. NJ0005622. March 4, 1999.

PSEG Nuclear LLC (Public Service Enterprise Group). 2006. PSE&G Permit Renewal Application Salem Generating Station. Permit No. NJ0005622.

PSEG Nuclear LLC (Public Service Enterprise Group). 2006a. Salem NJPDES Permit Renewal Application. Section 3– Request for Renewal of §316(a) Variance for the Salem Generating Station.

PSEG Nuclear LLC (Public Service Enterprise Group). 2006b. Salem NJPDES Permit Renewal Application. Section 4– Comprehensive Demonstration Study.

PSEG Nuclear LLC (Public Service Enterprise Group). 2006c. Salem NJPDES Permit Renewal Application. Section 5– Adverse Environmental Impact.

PSEG Nuclear LLC (Public Service Enterprise Group). 2006d. Salem NJPDES Permit Renewal Application. Section 6– Assessment of Alternative Intake Technologies.

PSEG Nuclear LLC (Public Service Enterprise Group). 2006e. Salem NJPDES Permit Renewal Application. Section 7– Restoration Production Estimates.

PSEG Nuclear LLC (Public Service Enterprise Group). 2019. PRA Part I. Salem Generating Station NJPDES Permit NO. NJ0005622 §316(b) REPORT PART I, Volume 1 of 2.Prepared for Public Service Electric and Gas Company (PSEG).

PSEG Nuclear LLC (Public Service Enterprise Group). 2019. Review and Screening of Technologies for Entrainment Reduction. Prepared for AKRF, Inc and Public Service Electric and Gas Company (PSEG). October 2019

PSEG Nuclear LLC (Public Service Enterprise Group). 2020. PRA Part 2 Draft. Salem Generating Station NJPDES Permit NO. NJ0005622 §316(b) REPORT PART 2 Draft, Volume 1 of 2.Prepared for Public Service Electric and Gas Company (PSEG).

Reading, H.H. 1982. Retention of juvenile White Sturgeon, *Acipensor transmontanus*, by perforated plate and wedge-wire screen materials. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary, University of California Technical Report. Pp 1-9.

Reid, D.G., R.J. Kynoch, L. Penny, K. Summerbell, A. Edridge, F.G. O'Neill. 2012. A comparison of the GOV survey trawl with a commercial whitefish trawl. Fisheries Research. 121-122: 136-143.

Ross, R. M., W. F. Krise, L. A. Redell, and R. M. Bennett. 2001. Effects of dissolved carbon dioxide on the physiology and behavior of fish in artificial streams. Environmental Toxicology 16:84–95.

RSMeans. 2019. Heavy construction costs with RSMeans data. Hale, D. (eds). Construction Publishers and Consultants. Rockland, MA. 740pp.

Secor, D.H., J.R. Waldman. 1999. Historical abundance of Delaware Bay Atlantic sturgeon and potential rate of recovery. American Fisheries Society Symposium 23: 203-216.

Simpson, P.C. 2008. Movements and habitat use of Delaware River Atlantic sturgeon. Master Thesis, Delaware State University, Dover DE. Pp. 128.

Stoot, L.J., D.P. Gibson, S.J. Cooke, M. Power. 2018. Assessing the potential for using low-frequency electric deterrent barriers to reduce lake sturgeon (*Acipenser fulvescens*) entrainment. Hydrobiologia. 813: 223-235.

Treanor, H.B., A.M. Ray, M. Layhee, B.J. Watten, J.A. Gross, R. E. Gresswell, M.A.H. Webb. 2017. Using carbon dioxide in fisheries and aquatic invasive species management. Fisheries. 42 (12): 621-628.

United States Environmental Protection Agency (USEPA). 2004. Final Rule. Final regulations to establish requirements for cooling water intake structures at Phase II existing facilities. 69 Fed. Reg. 41576.

Zielinski, D.P., V.R. Voller, J.C. Svendsen, M. Hondzo, A.F. Mensinger, P. Sorensen. 2014. Laboratory experiments demonstrate that bubble curtains can effectively inhabit movement of common carp. Ecological Engineering. 67: 95-103.