NMFS: Anadromous Salmonid Passage Facility Design
And
Columbia Generating Station: NPDES Comments,
Why Cylindrical Screens in Flowing Water Impinge and Entrain Few Fish and Its Importance for The Columbia Generating Station's Intake

Review and Evaluation

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Prepared For: The Energy Facility Site Evaluation Council

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INTRODUCTION

Washington Department of Fish and Wildlife (WDFW) has been tasked with providing a review and evaluation of the National Pollution Discharge Elimination System (NPDES) draft permit public comments submitted by Energy Northwest (EN) containing technical data related to National Marine Fisheries Service's (NMFS) Anadromous Salmonid Passage Facility Design (Manual), dated July 2011. Energy Northwest submitted *Why Cylindrical Screens in Flowing Water Impinge and Entrain Few Fish and Its Importance for The Columbia Generating Station's Intake* by Dr. Charles Coutant (2014; White Paper) as supporting information for the Columbia Generating Station (CGS) cooling water intake structure (intake). This review is the request of Energy Facility Site Evaluation Council (EFSEC) under contract # 13-1536 as follows.

> WDFW will provide technical services to EFSEC in support of the compliance monitoring (auditing) activities at the Hanford site for the CGS. This includes inspections, review of environmental monitoring data, bioassay studies, and NPDES permit conditions.
>
> 1. Review and evaluate design of CGS cooling water intake structure for consistency with National Marine Fisheries Service's (NMFS) Anadromous Salmonid Passage Facility Design Manual, dated July 2011.
> 2. Review and evaluate public comments submitted by Energy Northwest for functional equivalency to the above mentioned NMFS Manual.
> 3. Review and evaluate technical data contained in public comments, as requested by EFSEC.

As part of the contract, WDFW reviewed the design of the intake for consistency and functional equivalency with the NMFS Manual, specifically water diversion intake screen criteria to prevent fish injury and/or mortality. The Manual describes and provides criteria for cylindrical screens similar to the CGS intake screens under the section for end of pipe screens. Although not specifically described as criteria in the Manual, hydraulic bypass and behavioral avoidance have been incorporated by NMFS and these factors are relevant for reviewing the CGS intake. The Manual provides the following in the forward: "The task involved in successfully passing fish upstream or downstream of an in-river

impediment is a dynamic integration of fish behavior, physiology, and bio-mechanics with hydraulic analysis, hydrologic study, and engineering." Based on the information provided for WDFW's evaluation, the intake screen does not meet NMFS Manual standards and guidelines.

During the NPDES public review, EN submitted the White Paper to demonstrate that even though the intake does not meet the criteria, CGS intake system and the associated water withdrawal does meet the intent of the Manual: safe, timely, and efficient upstream and downstream passage of anadromous salmonids past the intake screens. Although the cylindrical screens do form a hydraulic bypass and fry may respond to the approach velocity, the screens do not provide physical exclusion. Based on the information provided for WDFW's evaluation, the CGS intake is not functionally equivalent with the Manual.

NMFS and Dr. Coutant concur that impingement and entrainment of aquatic organisms are important concerns for water withdrawals. In response to impingement and entrainment concerns, NMFS, Portland District, established criteria for design and construction of fish passage facilities and fish screening in the 1980s (updated 2011). No one facility or screen fits all applications and environments. Consequently NMFS identified criteria that will be applicable to multiple fish passage facilities and/or fish screening devises. Specifically, approach velocity and screen opening size criteria for fish screening were developed to provide protection for the weakest swimming species present, in their most vulnerable life stage, under adverse environmental conditions. It is expected that nearly all fish that encounter a fish screen designed to NMFS criteria will survive and the screen will approach 100% effectiveness. Criteria for pore size have been selected to keep the most vulnerable species from passing through the screen (entrainment) and low approach velocity (sometimes referred to as through-screen velocity) to prevent vulnerable species from being caught against the screen by the force of the water moving through the screen (impingement).

In the White Paper, Dr. Coutant offers that hydraulic bypass around a cylinder and fish avoidance behavior are sufficient mechanisms to prevent impingement and entrainment of fish at the CGS intake. He provides analysis of relevant scientific literature to support his position. Relevant literature includes laboratory and field studies testing fish screens, and fish behavior and biomechanics. This review will evaluate the applicability of the literature to NMFS criteria, site-specific biological conditions, and CGS intake features. In addition, the review will evaluate the conclusions made in the White Paper.

BACKGROUND

Columbia Generating Station Cooling Water Intake Structure

The CGS intake system was designed and constructed in the late 1970's and is currently in operation. The intake is a closed water cooling system with two cylindrical, passive, end-of-pipe screens. The cylindrical screens are perforated (Figure 1) with 3/8 inch diameter holes (0.375 inches, 9.5 mm) and have an open area of 40 percent. Each screen face is generally parallel to the river flow and the intake approach velocities are on the order of 0.2 – 0.4 feet per second (fps). The intake system is designed for a total withdrawal capacity of 25,000 gallons per minute (gpm; 55.7 cfs, 1.58 m^3/sec) where each pump has a capacity to withdraw 12,500 gpm (27.85 cfs, 0.79 m^3/sec). The average intake is approximately 20 million gallons per day (MGD; 31 cfs) and the average makeup water withdrawal is about 17,000 gpm (38 cfs, 1.1 m^3/sec).

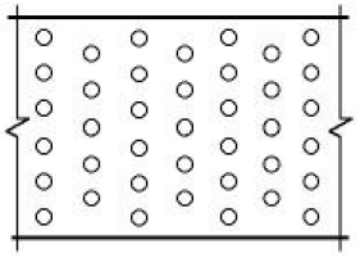

Figure 1. Example of perforations

Historically screens at intake structures were designed solely for debris removal and consisted of 3/8 inch galvanized wire mesh. The selection of screen size openings were generally based on removal of trash that could clog condenser tubes. Screen size openings became fairly standardized on a 3/8 inch within the power plant industry (Train et al. 1976).

NMFS 2011 Fish Screening Criteria

If designed today to meet NMFS fish screening criteria, many of the CGS intake system features would not require a redesign. The closed water cooling system and the shape and placement of the screens are proven technology. The pumps and the diversion capacity of 25,000 gpm are still applicable. Changes to meet NMFS 2011 fish screening criteria include changing screen perforation diameter and moving from a passive screen to an active screen that incorporates an airburst or other cleaning system. Approach velocity criterion changes from 0.2 fps for a passive screen to 0.4 fps for an active screen. These criteria values are within the approach velocity range reported for the CGS intake. The relevant NMFS criteria follow.

A passive screen should only be used when…the combined rate of flow at the diversion site is less than 3 cfs.

The CGS intake screens are passive screens, meaning they are juvenile fish screens without an automated cleaning system. One of the requirements for determining if a passive screen is appropriate is the combined rate of flow at the diversion site, which must be less than 3 cfs. For CGS, the average intake is approximately 31 cfs and the average makeup water withdrawal is about 38 cfs, both of which are well above the 3 cfs indicating an active screen is required to keep the screens free of any debris that will restrict flow area. Another of the requirements is if the site is not suitable for an active screen, due to adverse site conditions. Site conditions are suitable for active screens.

The approach velocity must not exceed 0.40 fps for active screens, or 0.20 fps for passive screens.

Given CGS intake system comprises of two end-of-pipe passive intake screens, the approach velocity criterion is 0.2 fps. The actual approach velocity for the CGS passive intake screens are on the order of 0.2 – 0.4 fps, therefore do not consistently meet the approach velocity criterion for passive intake screens. As noted above the CGS intake system does not meet the criteria for passive screens indicating active screens are appropriate. The approach velocity for active screens must not exceed 0.4 fps.

Circular screen face openings must not exceed 3/32 inch in diameter.

The CGS intake screens consist of an outer and inner perforated pipe sleeve. The outer sleeve has a 42 inch (107-cm) diameter sleeve with 3/8 inch (9.5 millimeter (mm)) diameter holes comprising of 40 percent of the surface area. The inner sleeve has a 36 inch (91-cm) diameter sleeve with 3/4 inch (19-mm) diameter holes over 7 percent of the surface area. The outer screen was designed to prevent debris and fish entrainment. The inner screen allows for uniform velocity across the screen face. The

Manual criteria for screen material states that circular screen face openings must not exceed 3/32 inch in diameter and percent open area must be at least 27%. Although the outer screen meets the percent open area, the perforations are four times larger than the Manual criterion.

Enercon (2010), referenced by Dr. Coutant, states that perforated pipe intakes are obsolete screening systems that predate cylindrical wedgewire (CWW) screens. Impingement and entrainment may be similar but perforated intakes often have head loss, and debris buildup leading to velocity distribution issues. Even though NMFS does not specify screening material, as a new technology relative to the 1970s CGS intake design and construction, wedgewire would be considered for any intake system designed today. NMFS slot criterion is 1.75 mm for screens similar to CWW.

RELEVANT SCIENTIFIC LITERATURE

The White Paper reviews the pertinent scientific information on the fluid dynamics of both a typical cylindrical screen in flowing water and a swimming fish, and points out the key sensory and behavioral features of fish. The literature sited in the White Paper can be categorized into two groups, 1) the efficacy of CWW screens and the mechanisms that explain how entrainment is avoided and 2) fish biomechanics and sensory systems to explain why mechanisms work. Many of the articles cross both groups but are categorized here to remain consistent with the White Paper.

Cylindrical Wedgewire Screens

Industry in the United States withdraws a significant amount of water for cooling purposes. In 1976 cooling water withdrawal was estimated to be 70 trillion gallons per year. Without infrastructure improvements, industrial point source water withdrawals will continue to affect aquatic ecosystems, potentially decreasing endangered species populations and reducing the production of sport and commercial fish and shellfish (Train et al. 1976). For this reason, industry and environmental regulators continue to seek technological improvements to reduce/prevent impingement and entrainment of aquatic organisms. Consequently laboratory and field examinations of CWW ensued.

CWW consists of V-shaped wedgewire bars that are welded to support rods at their point and are formed to maintain a uniform screen opening. The slot size is defined as the dimension of the opening between the wide ends of the wedgewire bars. Figure 4.9 from Enercon (2010) shows a detailed view of the wedgewire screening material but does not label the slot opening.

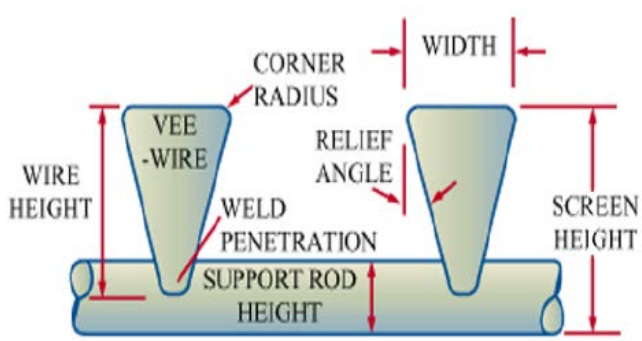

Figure 4.9 Wedgewire Screening Material

Literature Summary - Efficacy of CWW Screens

Dr. Coutant referenced several studies and applications of CWW screens in the White Paper and they are summarized in Table 1 below. The same parameters are provided for the CGS and NMFS fish screening criteria in Table 2 for comparison with the referenced studies.

Table 1. Review of relevant scientific literature for cylindrical wedgewire (CWW) cooling water intake screening found in Why Cylindrical Screens in Flowing Water Impinge and Entrain Few Fish and Its Importance for The Columbia Generating Station's Intake (Coutant 2014).

Facility/Literature Source	Existing/Study Lab, Field, Review	Location	Intake (MGD)	Ambient velocity (fps)	Screen Slot Size (mm)	Approach Velocity (fps)	Cleaning System	Fish size tested/in situ (mm)	Notes
Indian Point Energy Center (IPEC)									
Enercon, 2010[1]	Report: design criteria evaluation	Hudson River Estuary	1200 MGD	Flood: 1.0 Ebb: 2.1	9 mm 6 mm 3 mm 2 mm	0.25 fps 0.5 fps	N/A	N/A	New York State Department of Environmental Conservation staff indicated interest in through-slot velocities at or below 0.25 fps Final Recommendation CWW 2mm slot with cleaning system and 0.5 fps entrainment efficacy 89.8% Impingement efficacy 99.9%
NAI and ASA, 2011b	Lab			0.5 fps 1.0 fps 1.5 fps 2.0 fps	2 mm 6 mm	0.25 fps	N/A	Atlantic cod, Atlantic tomcod, carp, striped bass x white bass hybrid 3 to 21 mm (beads 1 mm)	Conducted flume tests utilizing ambient velocities within the range of the Hudson River Estuary and two slot sizes. Modeled results and produced entrainment probability curves. 2 mm screen Predicted Entrainment efficacy 80%
ASA and NAI, 2012	Field test	Hudson River Estuary		Flood: 1.0 Ebb: 2.1	2.0 mm	0.25 fps	N/A	37 different species- most common Striped bass, bay anchovy, white perch 2 to 24 mm	Tested CWW criteria from NAI and ASA, 2011a 2 mm screen, all species Entrainment efficacy 78%
Charles Point									
Enercon, 2010[1] Barnthouse et al., 2011[2]	Existing	Hudson River	55 MGD	Flood: 1.0 Ebb: 2.1	2.0 mm	0.5 fps	Yes	striped bass, white perch, Atlantic tomcod lengths not provided	efficacy of the full-scale CWW screens are similar to the efficacy predicted using Entergy's length-based model

Table 1. Continued

Facility/Literature Source	Existing/Study Lab, Field, Review	Location	Intake (MGD)	Ambient velocity (fps)	Screen Slot Size (mm)	Approach Velocity (fps)	Cleaning System	Fish size tested/in situ (mm)	Notes
IBM									
Enercon, 2010[1]	Existing	Hudson River	2075 MGD	Not provided	3 mm	Not provided	Yes	Not provided	Entrainment efficacy not provided
United Water New York									
AKRF, Inc. 2011 Barnthouse et al., 2011[2]	Field test	Haverstraw Bay in the Hudson River	N/A	50th percentile ranged from 0.63 fps to 1.12 fps	2 mm	0.5 fps	N/A	River herring, Atlantic tomcod, bay anchovy, Naked goby, Hogchoker, striped bass Size classes ranged from 2 mm to ≥ 25 mm	Estimates of entrainment reduction from the UWNY In-River Study (adjusted for larval avoidance of the control port) range from 57% to 80%
Oak Creek									
Enercon, 2010[1]	Existing	Lake Michigan	2698 MGD	Vertical movement	9.5 mm	0.5 fps	No	Not provided	Entrainment efficacy not provided
J. H. Campbell Power Plant									
NAI and ASA, 2011b Barnthouse et al., 2011[2]	Existing	Lake Michigan	837 MGD	Vertical movement	9.5 mm	0.38 fps	Not provided	yellow perch, slimy sculpin, alewife, spottail shiner, trout-perch, johnny darter lengths not provided	Because array creates spawning habitat for some fish species, overall entrainment may not be reduced Fish eggs, yellow perch, slimy sculpin larvae significantly higher densities in entrainment samples than in samples taken at nearby lake locations due to available spawning habitat

Table 1. Continued

Facility/Literature Source	Existing/Study Lab, Field, Review	Location	Intake (MGD)	Ambient velocity (fps)	Screen Slot Size (mm)	Approach Velocity (fps)	Cleaning System	Fish size tested/in situ (mm)	Notes
Zeitoun et al. 1981									
In Barnthouse et al., 2011[2]	Field test	Lake Michigan	N/A	Vertical movement	2 mm 9.5 mm	0.5 fps		rainbow smelt, yellow perch, alewife, carp, whitefish, herring/smelt, minnows lengths not provided	predict the effectiveness of the proposed intake for Unit No. 3 of the J. H. Campbell Plant all larvae no significant difference between larval densities entrained by the 2.0 mm and 9.5 mm screens all species except minnows, larval entrainment efficacy 91% to 100%
Eddystone Generating Station									
AKRF and NAI 2011 Barnthouse et al., 2011[2]	Existing	Delaware River Estuary	1,469 MGD	Not provided	6.35 mm CWW 9.5 mm Traveling screen	0.41 fps 0.88 fps	Not provided	American shad, bay anchovy, river herrings, striped bass, white perch Average lengths ranged from 10.2 mm to 20.4 mm	Compared CWW entrainment to traveling screen 6.35 mm CWW screens entrainment efficacy 78% lower than entrainment 9.5 mm (3/8-inch) mesh screens at adjacent Units Entrainment efficacies compared to ambient surveys exceeded 80% for all but two species
Otto et al. (1981): Mississippi River Study									
In Barnthouse et al. 2011[2]	Full scale field test	Side channel of Mississippi River	N/A	1.2 to 2.7 fps	1.0 mm	0.4 fps	N/A	clupeids, emerald shiner, carp, freshwater drum, crappie lengths not provided	Very few larvae longer than 8 mm were entrained Entrainment efficacy not provided

Table 1. Continued

Facility/Literature Source	Existing/Study Lab, Field, Review	Location	Intake (MGD)	Ambient velocity (fps)	Screen Slot Size (mm)	Approach Velocity (fps)	Cleaning System	Fish size tested/in situ (mm)	Notes
Weisberg et al. 1984, 1987									
In Barnthouse et al., 2011[2]	Field test	Patuxent River	N/A	Not provided	1 mm 2 mm 3 mm	0.66 fps	N/A	bay anchovy - 5 length classes naked goby - 4 length classes actual lengths not provided	Entrainment increased with increasing slot width, although not statistically significant. Real differences probably existed, but could not be detected because of the relatively low numbers of larvae entrained by all sizes of CWW screens. Entrainment efficacy larvae ≤4 mm 0% larger size classes, entrainment efficacy ranged from 62% to 100 %
Three EPRI field studies									
In Barnthouse et al., 2011[2]	Field test	Sakonnet River, arm of Narragansett Bay	N/A		1.0 mm 9.5 mm Control	0.5 fps 1.0 fps	N/A	Grubby, Sand lance, Winter flounder lengths not provided	0.5 mm or 1 mm slot widths reduced entrainment, 0.5 mm screens more effective than 1 mm winter flounder Estimated fraction entrainment efficacy 1 mm screen 80%
In Barnthouse et al., 2011[2]	Field test	Chesapeake Bay, MD,	N/A		1.0 mm	0.5 fps 1.0 fps	N/A	Bay anchovy, Naked goby, Northern pipefish, Skilletfish, Striped blenny lengths not provided	0.5 mm or 1 mm slot widths reduced entrainment, 0.5 mm screens more effective than 1 mm

Table 1. Continued

Facility/Literature Source	Existing/Study Lab, Field, Review	Location	Intake (MGD)	Ambient velocity (fps)	Screen Slot Size (mm)	Approach Velocity (fps)	Cleaning System	Fish size tested/in situ (mm)	Notes
Three EPRI field studies cont.									
In Barnthouse et al., 2011[2]	Field test	Portage River, OH (tributary to Lake Erie)	N/A		1 mm	0.5 fps 1.0 fps	N/A	Carp, Freshwater drum, Shad, Temperate basses lengths not provided	0.5 mm or 1 mm slot widths reduced entrainment, 0.5 mm screens more effective than 1 mm
Heuer and Tomljanovich 1978									
In Barnthouse et al., 2011[2]	Lab, Flat wedgewire panels	N/A	N/A	0.25 fps 0.5 fps 1.0 fps 2.0 fps	0.5 mm 1.0 mm 2.0 mm	0.25 fps 0.5 fps 0.75 fps	N/A	muskellunge, channel catfish, bluegill, largemouth bass, smallmouth bass, striped bass, walleye	Tested flat wedgewire panels

Enercon, 2010[1]: Evaluated existing literature and provided existing facility information in IPEC design review.
Barnthouse et al., 2011[2]: Utilized existing collection data available in literature to test NAI and ASA, 2011a probability curves.

Table 2. Applicable information from Columbia Generating Station and NMFS fish screening criteria for comparison with literature summary.

Facility/Literature Source	Existing/Study Lab, Field, Review	Location	Intake (MGD)	Ambient velocity (fps)	Screen Slot Size (mm)	Approach Velocity (fps)	Cleaning System	Fish size tested/in situ (mm)	Notes
Columbia Generating Station		Columbia River, Hanford Reach	20 MGD	3 fps to over 11 fps	9.5 mm perforated	0.2 fps – 0.4 fps passive screen	No	35 mm to 95 mm	Excludes salmonids larger than 75 mm body length
NMFS Criteria					2.3 mm perforated 1.75 mm slot	0.2 fps passive 0.4 fps active	No Yes		Excludes salmonids larger than 25 mm body length

Cylindrical wedgewire screens were tested in laboratory flumes, lakes, estuaries and rivers (Table 1). Slot size and approach velocity utilized in the tests and at existing facilities ranged from 0.5 mm to 9.0 mm and 0.25 fps to 1.0 fps respectively. Ambient velocity ranged from no horizontal velocity in lakes to 2.1 fps in estuaries and 2.7 fps in rivers. Laboratory flume velocities ranged from 0.5 fps to 2.0 fps. The fish species varied by location. American shad, Atlantic tomcod, bay anchovy, striped bass, white perch, river herrings were the focal species for studies relating to Indian Point Energy Center. Anadromous salmonids were not part of laboratory or field tests. Swimming ability for fish found in lakes, estuaries and rivers, and used in laboratory studies was not provided. Swimming ability is relevant for behavioral avoidance comparisons.

As a comparison, the CGS screens are a cylindrical metal tube with 9.5 mm perforations rather than wedgewire (Table 2). The approach velocity ranges from 0.2 fps to 0.4 fps which is within the ranges in the relevant literature. Ambient velocities in the Columbia River Hanford Reach vary from 3 fps to over 11 fps depending on the section and flow, well above the highest ambient velocity (2.7 fps) tested. Steelhead and fall, summer and spring Chinook are all present in the Hanford Reach at various points in their life stages. Zero-age fall Chinook collected in an array of fyke nets across the Hanford Reach ranged in size from 35 mm to 55 mm in April and 35 mm to 95 mm in June (Table 3).

Table 3: Screen mesh entrainment potential, as predicted by equations from Bell's Handbook. Highlighted rows are relevant life states and sizes for NMFS criteria and CGS intake exclusion.

Species	Body Length and Depth (mm)	Ratio Length/ Depth	Predicted minimum mesh (inches)	Protect w/ NMFS criteria?	Protect w/ CGS Screens?	Species/life stage present?
Emergent steelhead and Chinook fry	L=25, D=2.5	10.0	1/16th inch	maybe	no	unlikely
Button-up steelhead and Chinook fry	L=35, D =5	7	7/64th inch	yes	no	unlikely
Chinook zero-age	L=50, D=7.5	6.7	1/8th inch	yes	no	yes
Chinook subyearling	L=75, D=12	6.25	3/8th inch	yes	maybe	yes
Chinook subyearling	L=100, D=17	6.3	5/8th inch	yes	yes	yes
Wild steelhead pre-smolt	L=125, D=22	5.7	3/4th inch	yes	yes	yes
Hatchery steelhead smolt	L=150, D=25	6.0	1 inch	yes	yes	yes

NMFS criterion for slot and perforated screen openings are 1.75 mm and 2.3 mm respectively. The NMFS slot opening is within the range of the CWW slot openings used in studies and at existing facilities. Without a screen cleaning system the approach velocity criterion is 0.2 fps and with, 0.4 fps. Most study applications did not use a screen cleaning system. A few existing facilities have screen cleaning systems and the rest either did not have a system or it was not reported in the literature. For those systems and tests without a cleaning system 0.2 fps approach velocity would be applicable for comparison, for those with a cleaning system 0.4 fps. Charles Point and IBM facilities and NAI and ASA, 2011b and ASA and NAI, 2012 studies (Table 1) most closely meet NMFS criteria, although different fish species than what is found in the Hanford Reach were utilized in the studies and found in the Hudson River and estuary.

Literature Conclusions - Efficacy of CWW Screens and Mechanisms

Even though screening, approach velocities, fish, and site characteristics varied in the literature from the Hanford Reach and CGS, the basic concepts from the literature are relevant. Field studies found higher densities and length frequencies of eggs and larvae (ichthyoplankton) in the ambient water than passing through a control port. Higher densities and length frequencies were also seen moving through the control port than through the CWW screen. As noted by Dr. Coutant, these differences in the field and the laboratory results were attributed to four sequential events; hydraulic bypass, independent movement associated with avoidance, physical exclusion and sweeping velocity.

As water moves around a CWW, hydrodynamic and physical phenomena such as turbulence will move some eggs and larvae away from the screen. The lateral distance of an organism from the nose cone influences the effects of hydraulic bypass. Ichthyoplankton that have an approach path directly in line with the nose cone are less likely to be influence by hydraulic pass and are more likely to come in contact with the screen and water being withdrawn. Larvae and eggs with an approach path off set from the nose cone are more likely to be moved away from the screen. Figure 8-2 from NAI and ASA, (2011b) found below illustrates the principle.

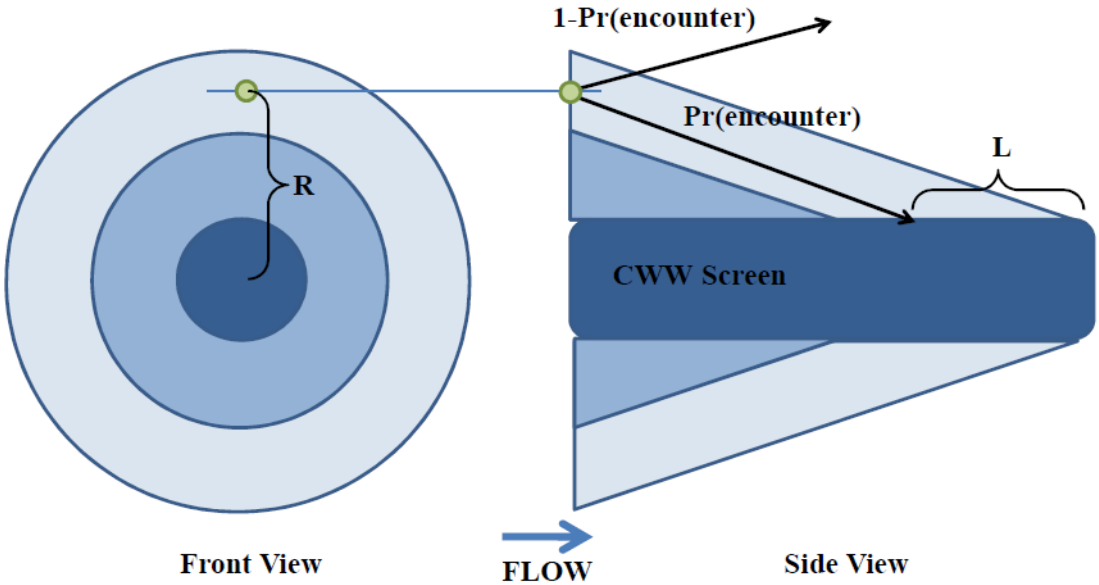

Figure 8-2. Conceptual model of particles (including fish eggs and larvae) approaching a CWW screen in flowing water. The probability that a particle approaching the screen encounters the face of the screen depends on the radial distance (R) the particle is from the screen axis as it approaches the screen. The length of screen remaining (L) from the point of encounter with the face of the screen and the end of the screen also depends on the location of the particle as it approaches the screen.

Organisms that do not bypass the intake screens may detect the screen and swim away from the water being withdrawn. The ability to avoid the screen is related to the organism size and swimming capabilities, and ability to detect the screen in time to make directed movements that lead to escape.

The third sequence of events is physical exclusion. Physical exclusion is based on the relationship of fish size to screen slot or perforation size. The screen will physically exclude any fish with a larger head size

than the screen openings. Head size has been correlated to length for multiple species at different life stages. Pore size is determined by the desired species and length to exclude from passing through a specific sized opening.

In the fourth event, organisms that are excluded may either remain on the screen (impingement), or be passively swept off the screen. Eggs and larvae that are not excluded will pass through the CWW screen.

The diagram produced in 2011 IPEC Wedgewire Screen Laboratory Study (NAI and ASA, 2011b) and found below presents the four sequential steps to avoid entrainment (Figure 2).

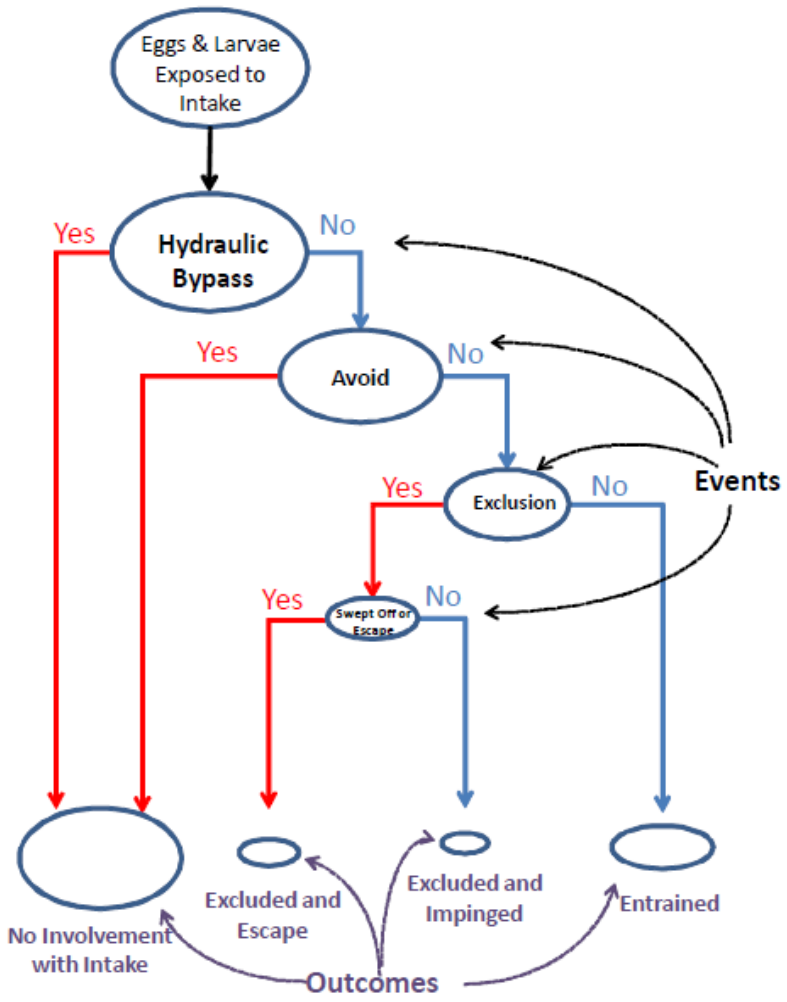

Figure 2. Four sequential steps to avoid entrainment and the resulting outcomes.

Dr. Coutant considered Eddystone Generating Station screen openings of ¼ in (6.35 mm), close to the 3/8-in (9.5 mm) opening size at CGS suggesting that the validation of the general model for entrainment reduction at Eddystone Generating Station would also be valid for CGS and the CGS intake screens would have similar entrainment results. Eddystone Generating Station has two types of screens at different units; Units 1 & 2 have 6.35 mm CWW screens and Units 3 & 4, 9.5 mm conventional traveling screens. In 122 paired entrainment samples from 20 April 2005 through 28 March 2006, the mean density of RIS (representative important species) larvae entrained through the 6.35 mm slot width CWW screens at Unit 1 and 2 was 78% lower than the mean density of larvae entrained simultaneously

through conventional 9.5 mm (3/8-inch) mesh screens at the adjacent Unit 3 and 4 CWIS. Given CGS screen size is similar to the traveling screen size, comparison of entrainment efficacy with the 6.35 mm screen size may not be applicable. Although 9.5 mm screen size is similar between the two facilities, screen type is not. Some portion of the density difference between the Eddystone Generating Station may be attributed to the hydraulic bypass and behavioral avoidance associated with cylindrical screens, such as that found at CGS facility. CWW entrainment efficacies at Eddystone Generating Station compared to ambient surveys in the Delaware River exceeded 80% for all but two species, but care should be taken if comparing CGS with Eddystone Generating Station given different screen size, material type, species and environmental conditions of the river systems. Even if CGS intakes have similar entrainment efficacy with similar fish and river conditions, approximately 20% of the fry will still be entrained. With an average of 96.2 million fry emerging from the Hanford Reach gravel each spring, at 80% efficacy, approximately 19.2 million fry will be entrained.

Fish Biomechanics Literature

In general, the fish anatomy and physiology papers discuss the sensory perception of the lateral line, free neuromasts and vision to identify objects and negotiate complex flow environments. As Dr. Coutant noted, the lateral line system detects flow velocity and acceleration by a series of sensory cells that are distributed on or just under the skin along the head and body. In addition he provided an explanation for how a steady flow becomes altered when it encounters a cylinder such that a high-pressure region (i.e. stagnation point where fluid velocity is zero) is established at the upstream side of the cylinder, and a stable low-pressure suction region is established (i.e. attached eddy) at the downstream side of the cylinder. Liao (2006, 2007) looks at how fish use the flows around an obstacle and body movement to hold and minimize energy expenditures. He examines how fish hold behind a cylinder and how vision and the lateral line are used to maintain their position.

Hassan (1992, 1993) developed mathematical models to predict the stimulus distribution on the surface of a fish produced by a moving object, taking into consideration the interaction between the fish's body and the object flow field. Hassan suggested that the fish use information from the canal sensory system to identify an object and control distance from the object.

Bevelhimer and Coutant (2008) examined a method to observe surface oriented migrating salmon using light tags. The paper stated their interest in examining the reaction of the fish to turbulence created by the debris boom and the baffle array but results were not provided in the paper. They noted that the behavior was evident when many fish drifted more slowly than known water velocities. Dr. Coutant provides in the White Paper: “An occasional fish swam close enough to the surface that we could see the fish itself and confirm that it was swimming head upstream. The fish showed a clear ability to detect the deflector well upstream of it…” and “The fish appeared to have altered their trajectory when they reached the beginning of the bow wave…” He summarized the relevance of the study as “…the significant ability of the steelhead to detect and avoid the deflector’s baffles well in advance of actually encountering the physical baffles.” Given the report only provided detailed information on the method to observe migrating fish, it was not possible to evaluate the information provided in the White Paper for this reference.

Coutant and Whitney (2000) evaluated the literature on fish behavior as it relates to passage of fish near or through hydropower turbines, specifically focusing on aspects of fish behavior that could be used for computational fluid dynamics (CFD) modeling of fish trajectories through turbine systems. Although the paper focused on passage through turbines, much of the information is applicable to passage past a CWW. Information provided by Coutant and Whitney (2000 and references therein) indicated fish exhibit different orientations under different circumstances.

Juvenile salmon in the Sacramento River (California) drifted downstream, tail first, keeping their heads upstream, experimental observations of coho salmon orient mostly upstream while drifting downstream and laboratory flume studies confirmed head-upstream swimming by Chinook salmon underyearling migrants. In contrast yearling or older sockeye salmon showed head first active downstream swimming and yearling Chinook salmon exhibited downstream swimming in the faster reaches of the river, but moved more slowly in slow reaches of the river. Dr. Coutant notes in the White Paper that migrate downstream in a head-upstream orientation minimizes energy requirements for downstream migration while providing stability control and the ability to respond quickly to environmental stimuli.

One conclusion found in their paper was that accelerating flow seems to influence the speed and likely the orientation of migration. Migrating juvenile salmon may use turbulent bursts, vortices, and waves in rivers in order to find regions of relatively high velocity to speed migration which would imply a sensory ability to detect turbulent features and use behavior to establish a beneficial orientation within turbulent flows. Although juveniles may identify and utilize turbulent flows, turbulence was also shown to reduce the flow velocity at which a fish is able to maintain itself in a current making the fish more susceptible to downstream displacement. In addition Coutant and Whitney (2000) concluded that the ability of fish to respond to external conditions is influenced by the stress condition of the fish. Nonsalmonids exposed to rapid temperature declines or prolonged cold weather become comatose or moribund and fish are not likely to exhibit avoidance or orientation behaviors causing them drift similar to passive particles.

Blaxter (1986 and references therein) provides a literature review of the development of sense organs and behavior for teleost larva. Salmonids are part of the infraclass of teleostei but a review of salmonid development literature is not provided in the paper. Blaxter (1986) writes “The substantial body of literature on young salmonids, which are larger and further developed at hatching has not generally been included.” (Blaxter 1986) limits the review to sensory systems and their role in behavior of larvae in the sea, specifically northern anchovy, Atlantic herring, Atlantic cod, and flatfish. References to salmonids include “Pacific salmon hatch at a more advanced stage and some rods [in the retinae] are present (Ali 1959 in Blaxter 1986)” and “Disler (1971) described the development of the free neuromasts and lateral line of sturgeon, chum salmon, and several freshwater percids and cyprinids. Generally the youngest larvae have a system of free neuromasts, including those segmentally arranged along the lateral body wall…the lateral line canals develop some time after hatching.” Free neuromasts are located at the surface of the skin providing a wide range of detection whereas canal neuromasts are located in the lateral line and have a more sophisticated range of detection. The review does not provide information on when free neuromasts and lateral line are developed in salmonids.

Teyke (1985 and references therein) examined the collision with and avoidance of obstacles in relation to the flow field hypothesis. The flow field around a swimming fish provides the hydrodynamic stimulus which leads to perception of obstacles in the environment of the fish. The flow field starts when a fish moves water by swimming and the field is altered by any obstacle near the fish. The shape and size of the fish's body and the velocity that the fish is traveling determines the amount of water moved. As a fish increases swimming speed, more water is displaced which increases stimulation to the lateral line. When the fish stops moving the flow field collapses and the fish cannot orientate itself to the object. But swimming blind cave fish collided with obstacles in front of them, violating the flow field hypothesis since a moving fish should always be able to detect the obstacles. One explanation for the collisions while swimming is that the sensitivity of the lateral line to respond to the change in flow field created by an obstacle is reduced to prevent

overstimulation from the swimming motions creating the flow field. Gliding from a certain distance rather than swimming stops motor activity, reducing overstimulation of the lateral line and the fish can detect obstacles and avoid collisions. The fish compensates to avoid overstimulation near obstacles. A downstream-migrating salmon fry or smolt will also compensate to avoid overstimulation to the lateral line in order to maintain its ability to detect objects. This may provide an explanation for why downstream-migrating fish have been observed swimming upstream at a rate slower than the ambient velocity as noted by Dr. Coutant.

Literature Conclusions - Fish Biomechanics

The fish biomechanics literature provided anatomical and physiological explanations for how fish identify objects. It is well understood that fish utilize their lateral line, free neuromasts and vision to identify objects and negotiate complex flow environments. The fish biomechanics literature does not address the potential response behavior of a fish once an obstacle has been identified. That connection is made in the efficacy literature for CWW screens.

EVALUATION CONCLUSIONS

After evaluating the information provided by Dr. Coutant in the White Paper, the essential questions appear to be: 1) does the CGS intake screens provide the maximum efficacy as they are now, or 2) will a change in slot size increase the efficacy of the intake screens? Although the literature shows cylindrical screens do form a hydraulic bypass and fry may respond to the approach velocity, the CGS screens do not provide physical exclusion. Caution should be taken when comparing study results found in the literature to the CGS intake given different screen size, material type, species and environmental conditions of the river systems. Based on the information provided for WDFW's evaluation, the CGS intake is not functionally equivalent with the Manual.

Literature showed hydraulic bypass and behavioral avoidance at CWW are major factors for entrainment prevention for larvae, with entrainment prevention by these factors increasing with larval fish size. Physical exclusion from the intake by pore size and approach velocity is not always the critical mechanism for entrainment protection but it is part of the entrainment equation. The appropriate screen size will reduce entrainment. The difference in densities and lengths moving through the control port compared to the ambient numbers reflects the hydraulic bypass and avoidance behavior of organisms (Figure 2). The difference between the control port and the intake screen represent the number and size of organisms too large to move through screen. A portion of the excluded fish will become impinged and die or swept off the screen face. The organisms impinged on a screen or entrained through a screen are most likely the weakest swimming species present, in a vulnerable life stage, and/or under adverse environmental conditions. The application of a smaller screen size and lower approach velocity is the next step to further reducing the amount entrained.

EPRI (2005) found that the variable that had the greatest effect on the difference between test and control densities was slot width. This field study also saw greater concentrations of larvae in the ambient water than the control port indicating the potential for hydraulic bypass and avoidance behavior, even though the authors did not attribute the difference to those mechanisms. The control port was covered with a 9.5 mm mesh which the authors thought was unlikely to provide any physical exclusion but behavioral avoidance of the control intake may occur.

This paper and others reviewed here indicated that comparing entrainment rates for the test and control intakes may underestimate the effectiveness of wedgewire screens relative to ambient

densities. This consideration is important for evaluating the effectiveness of a screen compared to base line conditions. For the evaluation of the CGS intake to determine if it is functionally equivalent with NMFS fish screening criteria, the comparison is not between the baseline and the screen but the efficacy of a 9.5 mm opening to the efficacy of a 2mm opening .For the species and conditions occurring during the EPRI (2005) study, slot width had a significant effect.

Results for EPRI (2005) differed from other studies in that ambient velocities did have a significant effect on entrainment density. Densities entrained usually increase as ambient velocity increased. The authors suggested that at a lower ambient velocity range larvae approaching the screen may still be able to orient and use the ambient current to avoid entrainment. Their results showed that larvae essentially became passive particles at ambient velocities approaching 3.3 fps suggesting that the ambient velocity may only improve the effectiveness of a screen to a certain point, beyond which it interferes with avoidance behavior. Ambient velocities within the Hanford Reach range from 3 fps to 11 fps, higher than the 3.3 fps reported. The fish species and likely swimming abilities are different but at some velocity point salmonid fry will act as passive particles and behavior avoidance will not be an option. At that velocity, slot size will become the important variable. What that velocity is was not available in the literature reviewed.

Dr. Coutant provides a scenario for salmon fry and smolts encountering a cylindrical screen based on the scientific literature. He identifies the sequential steps to avoid entrainment (Figure 2) but he omits the final outcome for potential entrainment. As provided in the scenario, mechanisms to prevent entrainment at the CGS intake consist of hydraulic bypass, and behavioral avoidance. The 3/8 inch screen openings are more appropriate for debris exclusion than fish exclusion. Some portion of fish larger than 75 mm may be impinged on the screen face and a portion of those will be removed by the sweeping velocity. The change in screen openings to 2mm (1.75 mm for wedgewire) will decrease the amount and size of organisms entrained to those less than 25 mm in length. The difference in entrainment between a 2 mm screen and a 9.5 mm screen may be best examined with a flume study.

As pointed out by Coutant and Whitney (2000), computational fluid dynamics (CFD) modeling of fish trajectories through turbine systems should consider fish stress and critical flow velocity. Since NMFS criteria for fish screening were developed to provide protection for the weakest swimming species present, in their most vulnerable life stage, and under adverse environmental conditions, any laboratory or field comparisons between NMFS fish screening criteria and the CGS should utilize zero-age and sub yearling Chinook between 35 mm to 100 mm in length, exposed to the lowest temperature recorded in the Hanford reach. Laboratory flume comparisons should be conducted with ambient velocities at various flows within the velocity range of the Hanford Reach, including at the critical flow velocity where fish can no longer use avoidance behavior (lose the ability to swim).

As noted in the White Paper, impingement and entrainment monitoring are part of the Ecological Monitoring Program. The object of the program is to provide an environmental data base which may be used to identify long-term trends and operational impacts in the areas of aquatic ecology, water quality, and terrestrial ecology. Inspections of the intake structures were conducted in March and July through November 1985. Divers inspect and report any fish impingement on or interaction with the intake structure, the need for maintenance, unusual conditions such as accumulation of submerged debris, and plugging of water entrance orifices by periphyton. Fish were not seen impinged on the CGS screen or entrained into the intake during the 1985 monitoring. Sponges had established several colonies on the intakes but had died back to normal abundance by the next survey. Although it was noted in the references provided that at no time

during the year did fouling by algae, insects, sponges or plastic debris impact proper operation of the intakes, it is not apparent if approach velocities were verified during the surveys to determine proper intake operation for fish. Data and measurement parameters would assist in determining the rigger of the impingement monitoring. Entrainment samples were collected from April through September 1985 and contained no fish, fish eggs, or larvae but clams, relic shells and a fresh water mussel were found at the TMU pump house during biofouling control monitoring indicating some entrainment does occur. The 1985 monitoring for impingement and entrainment provides a snapshot in time and may not be representative of actual conditions. Given the objective of the Ecological Monitoring Program is to provide an environmental data base which may be used to identify long-term trends and operational impacts, additional rigorous entrainment and impingement studies beyond the 1985 efforts would add towards monitoring long term trends.

Dr. Coutant concludes with "The fluid dynamics of a cylindrical screen in flowing water coupled with a fish's size-dependent ability to sense changes in the fluid dynamics of its surroundings (empowered by its own swimming motions) combine to nearly ensure that there will be little vulnerability of migrating fish larger than about 20 mm (0.8 in) to a porous cylindrical screen." In addition he provides "The hydraulics of a cylindrical screen would certainly deflect 50-75-mm-long Chinook salmon because the Alden flume studies indicated that hydraulic bypass was 90% effective for fish larvae 20 mm long (NAI and ASA 2011a)." After much researching to verify this point, it was determined that NAI and ASA (2011a)[1] was not actually provided (see footnote). The 2010 flume study determined the probabilities for hydraulic bypass, avoidance, impingement/sweep off, and entrainment for slot widths ranging from 2 to 9 mm, through-slot velocities of 0.25 fps and 0.5 fps, and ambient (sweeping) velocities of 0.25 fps, 0.5 fps, and 1.0 fps. Though requested, 2010 IPEC Wedgewire Screen Laboratory Study report was not actually provided so verification of the efficacy of 90% for a 20 mm fish and the parameters for those results was not possible. Dr. Coutant did not provide the slot width, through slot velocity and ambient velocity relative to the 90% efficacy. Information for the 9 mm screen at through-slot velocities of 0.25 fps and 0.5 fps would be applicable to the CGS intake but the ambient velocities in the Hanford Reach are significantly higher, fish species and swimming abilities are different and screen material is perforated rather than wedgewire. Caution should be taken when comparing results.

Dr. Coutant has provided compelling information for the efficacy of Cylindrical Wedgewire screens and the four sequential steps to avoid entrainment. Hydraulic bypass and avoidance behavior do reduce entrainment but slot size will determine the amount of entrainment and impingement. The fry that are not moved away from the screen through hydraulic bypass or avoidance behavior will come into contact with the screen. All fish that encounter the screen and have a head size smaller than the slot size will be entrained. Those with a larger head size may become impinged and die or swept off with possible injuries. The organisms that may be entrained or impinged are likely the weakest swimming species present, in their most vulnerable life stage, under adverse environmental conditions. Those are the species intended to be protected through the NMFS fish

[1] It was not until the final review of this paper that I realized that the file labeled NAI and ASA 2011a IPEC Wedgewire Screen Laboratory Study (2).pdf sent to me was not NAI and ASA (Normandeau Associates, Inc. and ASA Analysis & Communications, Inc.) 2011a. 2010 IPEC Wedgewire Screen Laboratory Study. Prepared for Indian Point Energy Center. Report R-21825.002. as listed in the references but rather NAI and ASA. 2011b. 2011 IPEC Wedgewire Screen Laboratory Study. Prepared for Indian Point Energy Center. Report R-21825.004. The file labeled NAI and ASA 2011b.pdf was ASA Analysis & Communication, Inc. 2011. Attachment 4 Evaluation of J. H. Campbell Studies of Cylindrical Wedgewire Screens. July 22, 2011. Prepared for Indian Point Energy Center. Unfortunately I did not receive NAI and ASA 2011a as requested. I have made every attempt to maintain Dr. Coutant's notation for the NAI and ASA papers herein.

screening criteria. Hydraulic bypass and avoidance behavior will not protect the weakest organisms from injury and/or mortality associated with impingement and entrainment, exclusion and low approach velocity are also necessary. The CGS intake will not prevent entrainment of fry less than 75 mm with the 9.5 mm perforations. Therefore WDFW has determined that the comments submitted by Energy Northwest do not support functional equivalency of the CGS intake with the NMFS Manual.

BIBLIOGRAPHY

AKRF, Inc. 2011. Comparison of Predicted Entrainment Reductions Based on Results from 2010 IPEC Wedgewire Screen Laboratory Study to Estimated Entrainment Reductions Based on Results from 2009 and 2010 United Water New York In-River Study. Prepared for Indian Point Energy Center.

AKRF and NAI (AKRF, Inc., and Normandeau Associates, Inc.). 2011. Assessment of the Efficacy for Reducing Entrainment of T-72 Cylindrical Wedgewire Screens Installed at Eddystone Generating Station. Prepared for Indian Point Energy Center.

Alam, S., F. E. Parkinson, and R. Hausser. 1974. Hanford Nuclear Project No. 2. Air and Hydraulic Model Studies of the Perforated Pipe Inlet and Protective Dolphin. LHL-599. Washington Public Power Supply System and Burns and Roe, Inc.

ASA Analysis & Communication, Inc. 2011. Attachment 4 Evaluation of J. H. Campbell Studies of Cylindrical Wedgewire Screens. July 22, 2011. Prepared for Indian Point Energy Center.

ASA and NAI (ASA Analysis & Communication, Inc., and Normandeau Associates, Inc.). 2012. 2012 Wedgewire Screen In-River Efficacy Study at Indian Point Energy Center. Prepared for Indian Point Energy Center.

Barnthouse, L., D. Heimbuch, and J. Young. 2011. Contextual Analysis of Previously Published Studies of Cylindrical Wedgewire Screen Efficacy. Prepared for Entergy Nuclear Operations, Inc.; Entergy Nuclear Indian Point 2, LLC; and Entergy Nuclear Indian Point 3, LLC, by LWB Environmental.

Bevelhimer, M.S., and C. C. Coutant. 2008. Light tags for observing behavior of surface- oriented migrating salmonids. American Fisheries Society Symposium 61:231-239.

Blaxter, J.H.S. 1986. Development of sense organs and behavior of teleost larvae with special reference to feeding and predator avoidance. Transactions of the American Fisheries Society 115:98-114.

Coutant, C. C. 2014. Why Cylindrical Screens in Flowing Water Impinge and Entrain Few Fish and Its Importance for The Columbia Generating Station's Intake. Prepared for Energy Northwest Richland, Washington

Coutant, C. C. 2014. Comments on NMFS letter of December 12, 2013 to Shannon Khounnala of Energy Northwest by Michael P. Tehan of NMFS, with its attached memorandum. Prepared for Energy Northwest, Richland, Washington.

Coutant, C. C., and R.R. Whitney. 2000. Fish behavior in relation to passage through hydropower turbines: A review. Transactions of the American Fisheries Society 129:351-380.

Enercon (Enercon Services, Inc.). 2010. Evaluation of Alternative Intake Technologies at Indian Point Units 2 & 3. Prepared for Entergy Nuclear Indian Point 2, LLC and Entergy Nuclear Indian Point 3, LLC.

EPA August 8, 2013. U.S. Environmental Protection Agency's Comments on Preliminary Draft National Pollutant Discharge Elimination System (NPDES) Permit for the Columbia

Generating Station, NPDES No. WA0025151. Letter from M. J. Lidgard, EPA to J. La Spina, Washington Energy Facility Site Evaluation Council.

EPRI. 2005. Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intakes. EPRI, Palo Alto, CA: 2005. 1010112.

Hassan, E. S. 1992. Mathematical description of the stimuli to the lateral line system of fish derived from a three-dimensional flow field analysis. II. The case of an oscillating sphere near the fish. Biological Cybernetics 66:453-461.

Hassan, E. S. 1993. Mathematical description of the stimuli to the lateral line system of fish derived from a three-dimensional flow field analysis. III. The case of gliding alongside or above a plane surface. Biological Cybernetics 69:525-538.

Liao, J. C. 2006. The role of the lateral line and vision on body kinematics and hydrodynamic preference of rainbow trout in turbulent flow. Journal of Experimental Biology 209:4077-4090. DOI:10.1242/jeb.02487.

Liao, J. C. 2007. A review of fish swimming mechanics and behavior in altered flows. Philosophical Transactions of the Royal Society 362:1973-1993. DOI:10.1098/rstb.2007.2082.

NMFS (National Marine Fisheries Service). 2011. Anadromous Salmonid Passage Facility Design. NMFS, Northwest Region, Portland, Oregon.

NMFS. August 6, 2013. Notice of concern regarding pre-public review draft of Energy Facility Site Evaluation Council (EFSEC)/Washington Department of Ecology (WDOE)'s proposed Columbia Generating Station (CGS) National Pollutant Discharge Elimination System (NPDES) Permit No. WA-002515-1 and accompanying Fact Sheet. [With two attachments: B. Nordlund, July 31, 2013 and August 7, 2013; see separate citations]. Letter to D. Opalski, EPA from B. Susumoto, NMFS.

NMFS. December 12, 2013. Letter of December 12, 2013 to Shannon Khounnala of Energy Northwest by Michael P. Tehan of NMFS, with its attached memorandum by Bryan Norlund.

NAI and ASA. 2011b. 2011 IPEC Wedgewire Screen Laboratory Study. Prepared for Indian Point Energy Center. Report R-21825.004.

Norlund, B. July 31, 2013. Entrainment and Impingement Potential for Salmonids at the Columbia Generating Station (CGS) Intake Screens. Memorandum for Hydro Division files. National Marine Fisheries Service, Portland, Oregon.

Norlund, B. August 7, 2013. Columbia Generating Station (CGS) – Intake Screeens Assessment and Recommendations for Modifications. Memorandum for Hydro Division files. National Marine Fisheries Service, Portland, Oregon.

NRC (U.S. Nuclear Regulatory Commission). 2011. Biological Assessment and Essential Fish Habitat Assessment, Columbia Generating Station License Renewal. Docket Number 50-397. Rockville, Maryland.

Teyke, T. 1985. Collision with and avoidance of obstacles by blind cave fish *Anoptichthys jordani* (Characidae). Journal of Comparative Physiology A 157:837-843.

Train, R. E., A. W. Breidenbach, E. P. Hall, and D. Barnes. 1976. Development Document for Best Technology Available for the Location, Design, Construction and Capacity of Cooling Water Intake Structures for Minimizing Adverse Environmental Impact. Effluent Guidelines Division, Office of Water and Hazardous Materials, U.S. Environmental Protection Agency, Washington, D.C.

WDFW 2014 NMFS: Anadromous Salmonid Passage Facility Design and Columbia Generating Station: Cooling Water Intake System Specifications Review and Evaluation. Prepared for the Energy Facility Site Evaluation Council.

WPPSS (Washington Public Power Supply System). 1985. Operational Ecological Monitoring Program for Nuclear Plant 2 1985 Annual Report. Report No. 850377. Richland, Washington.