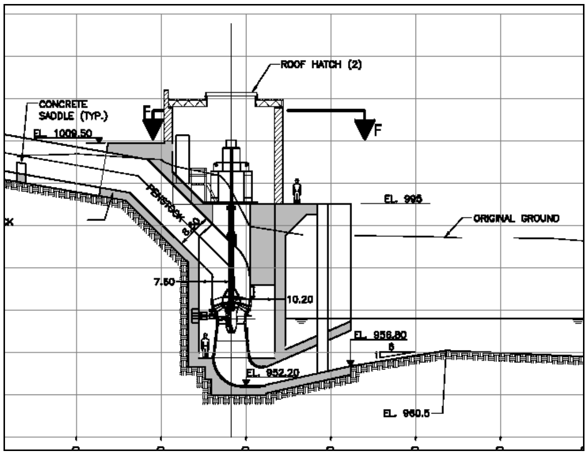
APPENDIX E.3.2

ESTIMATE OF TURBINE MORTALITY

Estimates of Turbine Mortality For Salmonids and Non-Salmonid Fish at Proposed Enloe Hydroelectric Project



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1 INTRODUCTION

The Okanogan Public Utility District (OKPUD) has submitted a draft license application (DLA) for construction of a new hydroelectric powerhouse to be located at the existing Enloe Dam on the Similkameen River in north-central Washington State (OKPUD 2007). The DLA was submitted to the Federal Energy Regulatory Commission (FERC) in November 2007. As part of the DLA, estimates of probable survival of fish passing through the proposed turbines were included. Survival estimates were made for a range of fish sizes representative of fish known to exist upstream of Enloe Dam. Although salmonids have not been found in the reservoir directly upstream of Enloe Dam in either 1991 or the current relicensing studies (OKPUD 2007), survival estimates for salmonids have been included for completeness. Rainbow trout are known to occur farther upstream in the Canadian reach of the Similkameen River and mountain whitefish are known to be present upstream of the reservoir (OKPUD 2007). The estimates appeared in Tables E.3-6 and E.3-7 of the DLA for non-salmonid and salmonid species, respectively. These tables are repeated below as Tables 1 and 2. Note that Table 2 has some minor changes from the survival ranges originally provided in Table E.3-7 of the DLA. This is due to some minor refinements made to the calculation methodology in the preparation of this document.

Table 1: Estimated Non-Salmonid Survival through Proposed Turbines

Fish Length	**Turbine Survival Estimate**
50 mm (approximately 2 inches)	95.3% +/- 3.2%
100 mm (approximately 4 inches)	91.0% +/- 6.4%
150 mm (approximately 6 inches)	87.2% +/- 9.6%

Table 2: Estimated Salmonid Survival through Proposed Turbines

Fish Length	**Turbine Survival Estimate**
50 mm (approximately 2 inches)	92.2% +/- 4.0%
100 mm (approximately 4 inches)	88.7% +/- 6.6%
150 mm (approximately 6 inches)	84.0% +/- 9.6%
250 mm (approximately 10 inches)	73.2% +/- 16.1%

These estimates were calculated based on a predictive equation and methodology developed as part of the U.S. Department of Energy Advanced Hydropower Turbine System Program (AHTSP). In their review comments to the DLA, the FERC requested supporting calculations that show how these estimates were derived. This document is intended to address this request.

2 AHTSP TURBINE SURVIVAL PREDICTIVE METHODOLOGY

2.1. Potentially Injurious Hydraulic and Physical Conditions

The risk of mortality associated with fish passage through a turbine is a function of the hydraulic and physical conditions that would be experienced by the fish during the passage. In the early stages of the AHTSP the Department of Energy contracted a study to investigate these various conditions and develop predictive equations for estimating survival given the specific parameters of a given turbine (Franke, et. al. 1997). The goal was to develop a tool that could be used to evaluate the potential for improvements with new innovative turbine designs. However, the tool can also be used to investigate the probable survival of fish passing through conventional turbine designs.

A brief summary of the hydraulic and physical conditions that were found to have potential negative impact on fish during turbine passage include:

- **Strike** – Physically contacting solid structures at high velocity. This could include striking turbine blades, wicket gates, stay vanes, or other mechanical or fixed components within the turbine environment.
- **Shear** – Exposure to a transition zone between two bodies of water that are moving at different velocities. If a fish is in a body of water that is moving at a constant velocity then the fish will also move at that velocity and there will be no negative impacts on the fish regardless of the magnitude of the velocity. However, if a fish moves into a transition zone where velocities are significantly varying over small lateral distances then the fish can experience significantly different velocities on either side of its body at the same time. This can tear off scales or rip open portions of the operculum, or even bruise tissue on the fish.
- **Grinding** – Getting caught between moving and stationary mechanical components of a turbine. This can result in injury due to pinching or bruising, or can result in complete severing of the body.
- **Turbulence** – This is generally associated with areas where large amounts of energy are dissipated through rapid mixing of flows, typical in plunge pools and stilling basins below spillways or water falls. Exposure to turbulent conditions can result in disorientation of the fish leaving them exposed to a greater risk of predation. Turbulence also exists within turbine passage environments, generally within the draft tube where the flow is decelerating and spreading out; however to a lesser extent than in a plunge pool because energy lost to turbulence is not available for power production so a well designed draft tube will minimize the turbulence to maximize the power production.
- **Cavitation** – In localized areas of extreme high velocities the effective water pressure can fall to well below atmospheric pressure and drive gas out of solution, forming small air bubbles in the flow. As these bubbles move back into more normal pressure zones they rapidly collapse which results in localized shock waves that can at times be strong enough to cause pitting in the steel blades of turbines. If a fish is immediately adjacent to a cavitating air bubble the associated shock wave can be extremely injurious. Due to the potential for damage to the turbine, cavitation is generally avoided and when it does occur it is typically

the result of poor turbine design, aging or poorly maintained turbines, and/or incorrect operations.

- **Pressure Changes** – Rapid pressure changes typical in passage through high-head turbines can result in bursting of the swim bladder or blood embolisms. Some species of fish are more susceptible to these effects than others due to their physiology, with salmonids being more resistant to problems associated with pressure changes than are perch or bass, for example. The potential for injuries associated with gas embolisms can be compounded by high levels of dissolved gasses in the water (see discussion under the following bullet).
- **Dissolved Gas Levels** – The presence super-saturated levels of total dissolved gasses (TDG) in the forebay upstream of the intake may compound the effects of rapid pressure change by causing nitrogen bubbles to develop in the bloodstream upon rapid depressurization, similar to a diver getting the bends by rising too fast.

2.2. AHTSP Predictive Mortality Equation for Kaplan Turbines

Mortality studies have been performed at a large number of hydroelectric turbines throughout North America. Study methods have varied over the years, and to some extent have likely influenced the results. Earlier studies generally involved tailrace netting in which a fyke net was set up downstream of the draft tube discharge and all the fish exiting the turbine were captured and inspected. More recently, turbine mortality studies have generally made use of the HI-Z balloon tag. This is a tag with a small deflated balloon that is attached to the fish before it is injected into the turbine flow. The balloon contains a mixture of ingredients that allow for a time-delayed inflation to occur after the fish has passed through the turbine. The fish is then buoyed to the surface in the tailrace by the inflating balloon and is retrieved by boat for inspection. This removes the potential problem of fish being injured or killed by the fyke net, and then having that injury attributed to passage through the turbine.

As part of the development of the turbine passage survival/mortality predictive equations, the AHTSP study group compiled hundreds of turbine mortality study results. In addition, information was gathered for each site concerning turbine characteristics so that the biological study results could be correlated to actual estimated conditions experienced. Kaplan and Francis turbines were considered separately in the review, since these are different turbine designs and understandably result in very different impacts on fish passing through them. The predictive equation for mortality/survival through Kaplan turbines was used to estimate the likely survival rate through the proposed turbines for the Enloe Project.

The predictive equation for Kaplan turbines uses turbine size, rotational speed, number of blades, flow rate, and the length of the fish entrained to estimate the probability that a fish of a given size will come near to or in contact with a structural element as it passes through the turbine. Strike, shear, grinding and cavitation (if it occurs) all are most pronounced very near to or in contact with the turbine blades or other fixed components of the turbine. The equation also adjusts the estimate for head and mechanical efficiency of the turbine. The magnitude of potential pressure changes are directly related to the head across the turbine, and the level of turbulence is generally well correlated to the mechanical efficiency (turbine shaft output power divided by the total power difference in the water flow above and below the project), with lower efficiencies generally representing higher levels of turbulence in the system and higher efficiencies resulting from minimal levels of turbulence. The one potentially hazardous condition listed in Section 2.1 above that is not addressed with this approach is the potential aggravating factor of having the fish exposed to supersaturated levels of TDG prior to passage through the turbine. This should not be of concern at Enloe Dam, since there does not appear to be any features upstream in the Similkameen River that would produce high levels of TDG in the Enloe forebay, although elevated levels of TDG have been detected downstream of Enloe during periods of heavy spill over the dam. Finally, a correlation factor is developed that correlates actual field mortality measurements to the calculated probability estimate. Obviously, this factor will be different for different species and types of fish, as some species of fish fare better passing through turbines than others. The predictive equation developed for Kaplan turbines is fairly complicated and is provided with description below:

M = (Lambda)*(N*L/D)*[cos a_a/(8*Q_{wd}) + sin a_a/(pi*(r/R))]

Where: M = Estimated Mortality Rate
N = Number of Turbine Blades
L = Fish Length (m)
D = Turbine Diameter (m)
Q_{wd} = Discharge Coefficient = Q/(w*D^3)
Q = Turbine Flow Rate (m^3/s)
w = Rotational Speed (radians/s) [= rpm*2*pi/60]
r = Distance Out from the Axis of Turbine to the Fish (m)
R = Maximum Radius of the Turbine (m)
Therefore, the ratio (r/R) represents the relative position of the fish with:
r/R = 0.50 being relatively close to the turbine hub,
r/R = 0.75 being about mid-span of the turbine blade, and
r/R = 1.0 being at the outer tip of the turbine blade
The angle a_a is obtained from: tan a_a = pi*E_{wd}*n/(2* Q_{wd}*(r/R)) where:
n = Turbine Efficiency
E_{wd} = Energy Coefficient = g*H/(w*D)^2
with: g = Acceleration of Gravity (9.81 m/s^2)
H = Net Head on Turbine (m)
Lambda = Mortality Correlation Factor

The morality correlation factor (lambda) is a factor that correlates actual field mortality studies to the probability that a fish of a given length would encounter injurious hydraulic or mechanical conditions upon passage through the turbine, most notably contact with a turbine blade, which is what the remainder of the equation calculates. In nearly all cases the value of lambda is found to be significantly lower than 1.0. This makes sense because the remainder of the equation is based solely on the physics of the water flow through the turbine and the space between the blades relative to a randomly located fish of a given length. Whereas in reality the fish are unlikely to be entirely randomly located within the water passage, but rather would tend to be moved toward and oriented with the highest velocity flow, which is centered between the blades and represents the safest place to be upon passage. In addition, even if fish do come in near proximity to, or even contact, a turbine blade it does not necessarily mean that every fish experiencing this would be killed or even injured.

3 APPLICATION OF THE PREDICTIVE METHODOLOGY TO ENLOE

3.1. Characteristics of the Proposed Enloe Project Turbines

Table 3 provides the turbine characteristics of the proposed Kaplan turbines for the Enloe Project. This information was provided by Christensen Associates, Inc. (CAI 2006). These were used for the purposes of estimating the mortality/survival of passage.

Table 3: Physical Characteristics of the Proposed Enloe Turbines

Number of Blades – N	6
Turbine Diameter – D	1.93 m (6.3 ft)
Flow Rate – Q	22.66 m^3/s (800 cfs)
Rotational Speed – w	37.7 radians/s (360 rpm)
Discharge Coefficient – $Q_{wd} = Q/(w*D^3)$	0.0836
Net Turbine Head – H	22.35 m (73.3 ft)
Energy Coefficient – $E_{wd} = g*H/(w*D)^2$	0.0414
Rated Turbine Efficiency – n	0.92

The first step was to determine if the influence of fish radial location relative to the full turbine radius (r/R) had a significant enough impact to justify performing individual survival estimates for different locations. Three values of the ratio r/R (0.50, 0.75, and 1.0) were input into the equations to determine the relative influence. The results were as follows:

r/R = 0.50: Angle $a_a = \tan^{-1}$ [3.14*0.0414*0.92/(2*0.0836*0.50)] = 55.0 degrees
[(cos 55.0)/(8*0.0836) + (sin 55.0)/(3.14*0.50)] = 0.857+0.522 = **1.38**

r/R = 0.75: Angle $a_a = \tan^{-1}$ [3.14*0.0414*0.92/(2*0.0836*0.75)] = 43.6 degrees
[(cos 43.6)/(8*0.0836) + (sin 43.6)/(3.14*0.75)] = 1.082+0.293 = **1.38**

r/R = 1.0: Angle $a_a = \tan^{-1}$ [3.14*0.0414*0.92/(2*0.0836*1.0)] = 35.6 degrees
[(cos 35.6)/(8*0.0836) + (sin 35.6)/(3.14*1.0)] = 1.216+0.185 = **1.40**

These results show that the radial location of the fish does not have a significant influence on the estimated mortality value, at least from a calculation standpoint. In reality, some recent field studies have shown that, depending upon the size of the fish relative to the size of the gaps that may be present between the turbine blade and the hub and/or the turbine blade and the discharge ring at the blade tip, there can be some variation in mortality rates based on the position of passage relative to the blade. However, even in these rare studies where passage position has been predicted based on release position of the fish upstream of the turbine, the variation in mortality rates is relatively minor. If the goal was to assess probable mortality based on passage position, then the best way to express this in the equation would in the mortality correlation factor (lambda), assuming adequate studies performed to this level of detail existed from which to extract species and fish length specific factors relative to turbine passage position. However, since the goal of this task is to assess the probable average mortality/survival for all the fish passing the turbine, regardless of position, it seems reasonable to estimate the average mortality rate using a generic value of r/R = 0.75 consistently. Multiplying in the final two known fixed values (number of blades and turbine diameter) results in the following value:

$$M = (\text{Lambda})*L*(6/1.93)*1.38 = 4.29*(\text{Lambda})*L$$

3.2. Establishing Correlation Factors from Past Study Results

Correlation factors (lambda) were developed separately for salmonids and non-salmonid fish. This is because significant differences in body shape and physiology result in different levels of susceptibility to certain hazardous conditions upon passage through turbines, with everything else being equal. The compilation of field study results and associated turbine characteristics provided in the AHTSP study report (Franke, et al. 1997) was searched for past studies that appear representative of the proposed conditions at Enloe.

3.2.1 Non-Salmonid Species

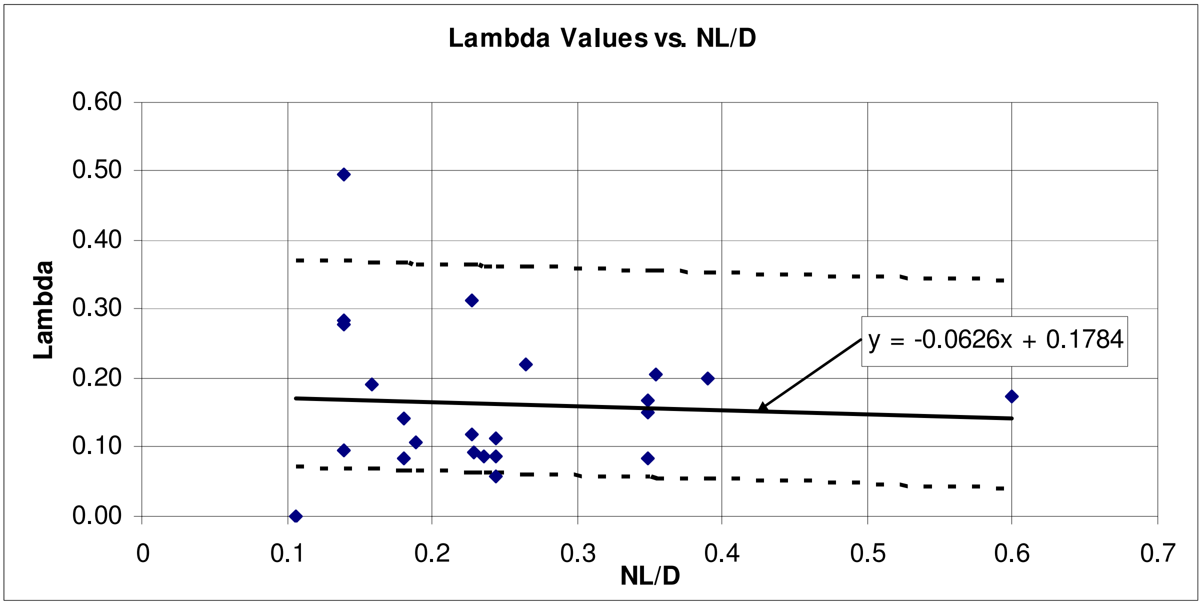
For non-salmonid species, 23 studies at 5 sites were used to back-calculate values for lambda. Information concerning these studies is provided in Table 4. This information was entered into the predictive equation along with the known fish mortality results (1.0-survival rate). Turbine efficiencies were not provided in the AHTSP study report, but were assumed to be 90% for the purposes of deriving lambda values. Sensitivity analysis of turbine efficiency values between 80% and 95% found that this parameter had insignificant impact on the calculated lambda value. Assuming a consistent fish passage position ratio of r/R = 0.75, lambda was the only unknown remaining in the equation, which could then easily be calculated. Calculated lambda values are provided in the last column of Table 4.

The calculated lambda values were plotted versus the non-dimensional ratio NL/D. This ratio provides a numeric variable relating fish length to blade spacing. Figure 1 is a plot of the lambda values versus NL/D. The solid line is a best fit linear relationship, and the dashed lines above and below were added to incorporate most of the values. The solid line has an equation of lambda = -0.0626*(NL/D) + 0.1784. The upper line is parallel and 0.2 higher, and the lower line is parallel and 0.1 lower. The equations for these lines are lambda = -0.0626*(NL/D) + 0.3784, and lambda = -0.0626*(NL/D) + 0.0784, respectively. These upper and lower line equations were used to calculate the maximum and minimum probable lambda values for non-salmonid fish of any given length passing through the Enloe turbines, with N=6, D=1.93 meters, and L is the fish length expressed in meters. The value given in Table 1 for a particular fish length is the average of the maximum and minimum, and the range is then expressed as a percentage above and below this average. A spreadsheet was developed to calculate the lambda values from the existing study results, produce the plot and relationship in Figure 1, and perform the calculations for the survival estimates through the Enloe turbines.

Table 4: Survival Study Results for Non-Salmonid Species

Location	Species	Fish Length (m)	Flow (m^3/s)	No. of Blades	Head (m)	Rot. Speed (rad/s)	Dia. (m)	Percent Survival (1 Hr.)	Calculated Lambda Coefficient
Chalk Hill, MI-WI	Bluegill	0.103	37.7	4	8.8	15.7	2.59	97.0	0.19
	Bluegill	0.153	37.7	4	8.8	15.7	2.59	98.0	0.09
Craggy Hill, NC	Bluegill	0.100	5.7	4	6.4	24.0	1.75	96.0	0.09
	Bluegill	0.155	5.7	4	6.4	24.0	1.75	86.0	0.21
Feeder Dam, NY	Shiner	0.088	29.5	6	6.7	12.6	2.92	96.8	0.14
	LM Bass	0.088	29.5	6	5.5	12.6	2.92	98.0	0.09
	LM Bass	0.190	29.5	6	5.8	12.6	2.92	90.0	0.20
	LM Bass	0.292	29.5	6	6.1	12.6	2.92	86.8	0.17
	Bluegill	0.092	29.5	6	4.7	12.6	2.92	97.3	0.11
	Bluegill	0.129	29.5	6	5.2	12.6	2.92	92.3	0.22
Herrings Dam, NY	Perch	0.100	34.0	4	5.8	14.5	2.87	91.1	0.50
	Perch	0.100	34.0	4	5.8	14.5	2.87	94.9	0.28
	Perch	0.175	34.0	4	5.8	14.5	2.87	98.2	0.06
	Perch	0.250	34.0	4	5.8	14.5	2.87	96.2	0.08
	Centrarchid	0.100	34.0	4	5.8	14.5	2.87	98.3	0.09
	Centrarchid	0.175	34.0	4	5.8	14.5	2.87	97.3	0.09
	Centrarchid	0.250	34.0	4	5.8	14.5	2.87	93.2	0.15
	Centrarchid	0.100	34.0	4	5.8	14.5	2.87	95.0	0.28
	Centrarchid	0.175	34.0	4	5.8	14.5	2.87	96.4	0.11
	Centrarchid	0.250	34.0	4	5.8	14.5	2.87	92.5	0.17
Townsend Dam, PA	LM Bass	0.217	42.5	3	4.9	15.9	2.87	96.8	0.12
	LM Bass	0.102	22.7	3	4.9	15.9	2.87	100.0	0.00
	LM Bass	0.217	22.7	3	4.9	15.9	2.87	86.0	0.31

Figure 1: Relationship between Lambda and NL/D for Non-Salmonid Species



Three fish lengths were considered as representative of the range of non-salmonids likely to be present above Enloe Dam (50mm, 100mm, and 150mm). The following calculations were used to develop the probable survival ranges shown in Table 1.

For 50 mm, L=0.05 m and NL/D=0.155. Maximum and minimum lambda values are 0.369 and 0.069, respectively. Entering these lambda values into the mortality equation results in M_{max}=4.29*0.369*0.05=0.079 and M_{min}=4.29*0.069*0.05=0.015, or a survival estimate range of 92.1% to 98.5%. This range is expressed in Table 1 as a probable survival of **95.3% +/- 3.2%**.

For 100 mm, L=0.10 m and NL/D=0.311. Maximum and minimum lambda values are 0.359 and 0.059, respectively. Entering these lambda values into the mortality equation results in M_{max}=4.29*0.359*0.10=0.154 and M_{min}=4.29*0.059*0.10=0.026, or a survival estimate range of 84.6% to 97.4%. This range is expressed in Table 1 as a probable survival of **91.0% +/- 6.4%**.

For 150 mm, L=0.15 m and NL/D=0.466. Maximum and minimum lambda values are 0.349 and 0.049, respectively. Entering these lambda values into the mortality equation results in M_{max}=4.29*0.349*0.15=0.225 and M_{min}=4.29*0.049*0.15=0.032, or a survival estimate range of 77.5% to 96.8%. This range is expressed in Table 1 as a probable survival of **87.2% +/- 9.6%**.

3.2.1 Salmonid Species

Considerably more effort has been placed on the study of salmonid survival through turbines than non-salmonids. As a result, there is more existing information concerning the results of field studies with salmonid species. In this case, 49 studies at 14 sites were used to back-calculate lambda values for salmonids. Information concerning these studies is provided in Table 5. As was the case with the non-salmonids, turbine efficiencies were not provided in the AHTSP study report, but were assumed to be 90% for the purposes of deriving lambda values.

Additionally, a consistent fish passage position ratio of r/R = 0.75 was assumed. The same process described for the non-salmonid species was performed, with the calculated salmonid lambda values provided in last column of the table.

Table 5: Survival Study Results for Salmonid Species

Location	Species	Fish Length (m)	Flow (m^3/s)	No. of Blades	Head (m)	Rot. Speed (rad/s)	Dia. (m)	Percent Survival (1 Hr.)	Calculated Lambda Coefficient
Big Cliff, OR	Chinook	0.100	52.5	6	27.7	17.1	3.76	91.1	0.43
	Chinook	0.100	52.5	6	27.7	17.1	3.76	92.2	0.38
	Chinook	0.100	71.1	6	24.7	17.1	3.76	94.5	0.27
	Chinook	0.100	71.1	6	24.7	17.1	3.76	89.8	0.50
	Chinook	0.100	71.1	6	21.6	17.1	3.76	89.7	0.48
	Chinook	0.100	71.1	6	21.6	17.1	3.76	90.6	0.44
	Steelhead	0.152	71.1	6	21.6	17.1	3.76	90.4	0.30
Essex, MA	At. Salmon	0.288	124.6	3	8.8	13.5	4.00	98.0	0.10
Feeder Dam, NY	Brown Trout	0.206	29.5	6	6.7	12.6	2.92	86.4	0.26
Foster, OR	Chinook	0.120	22.7	6	26.2	26.9	2.54	82.1	0.43
	Chinook	0.130	22.7	6	30.8	26.9	2.54	92.7	0.18
	Chinook	0.120	22.7	6	33.5	26.9	2.54	91.2	0.24
Hadley Falls, MA	At. Salmon	0.285	118.9	5	15.8	13.4	4.32	93.7	0.17
Herrings, NY	Salmonids	0.100	34.0	4	5.8	14.5	2.87	90.0	0.56
	Salmonids	0.175	34.0	4	5.8	14.5	2.87	87.5	0.40
	Salmonids	0.250	34.0	4	5.8	14.5	2.87	96.2	0.08
	Salmonids	0.100	34.0	4	5.8	14.5	2.87	95.5	0.25
	Salmonids	0.175	34.0	4	5.8	14.5	2.87	98.7	0.04
	Salmonids	0.250	34.0	4	5.8	14.5	2.87	98.6	0.03
Lowell, MA	At. Salmon	0.265	127.4	5	11.9	12.6	3.86	88.5	0.41
Lower Granite, WA	Chinook	0.134	594.7	6	29.9	9.42	7.92	94.6	0.51
	Chinook	0.148	538.1	6	29.9	9.42	7.92	94.6	0.44
	Chinook	0.151	509.8	6	29.9	9.42	7.92	94.9	0.39
	Chinook	0.150	509.8	6	29.9	9.42	7.92	95.3	0.36
	Chinook	0.151	509.8	6	29.9	9.42	7.92	97.5	0.19
	Chinook	0.150	509.8	6	29.9	9.42	7.92	97.5	0.19
	Chinook	0.148	382.3	6	29.9	9.42	7.92	97.2	0.19

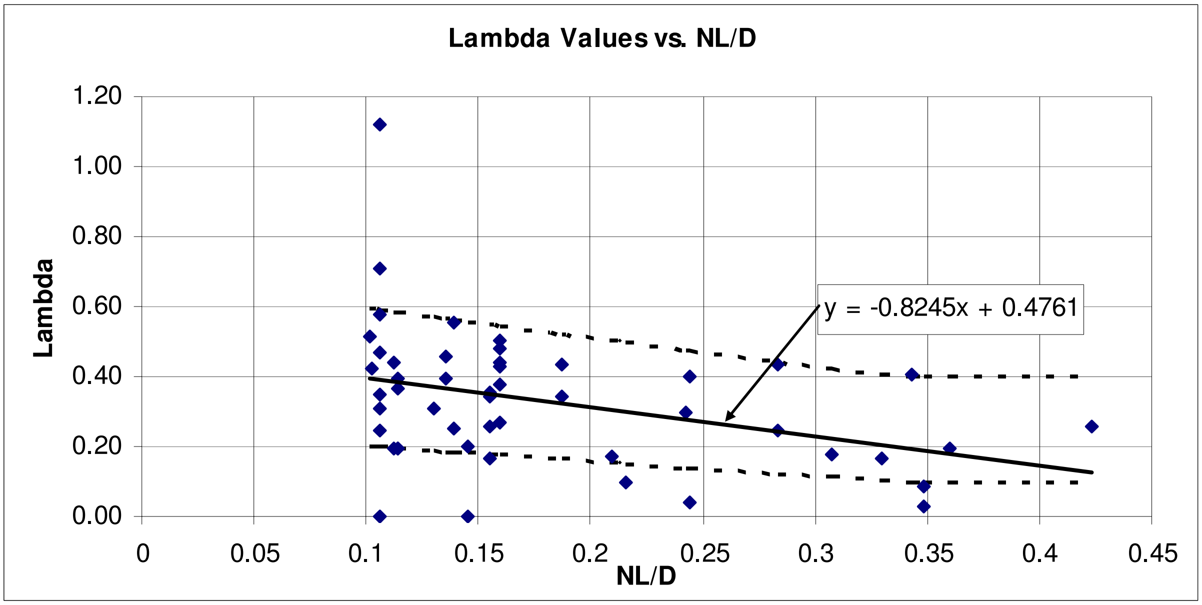
Table 5: Survival Study Results for Salmonid Species

Location	Species	Fish Length (m)	Flow (m^3/s)	No. of Blades	Head (m)	Rot. Speed (rad/s)	Dia. (m)	Percent Survival (1 Hr.)	Calculated Lambda Coefficient
Rock Island, WA	Chinook	0.179	481.5	4	12.2	8.97	7.01	96.1	0.42
	Chinook	0.179	481.5	6	13.7	10.5	5.74	95.0	0.44
	Chinook	0.179	481.5	6	13.7	10.5	5.74	96.1	0.34
Rocky Reach, WA	Chinook	0.161	453.1	6	28.0	9.42	7.11	94.7	0.40
	Chinook	0.161	453.1	6	28.0	9.42	7.11	93.9	0.46
	Chinook	0.184	396.5	6	28.0	9.42	7.11	97.3	0.16
	Chinook	0.184	396.5	6	28.0	9.42	7.11	94.4	0.34
	Chinook	0.184	396.5	6	28.0	9.42	7.11	94.2	0.35
	Chinook	0.184	396.5	6	28.0	9.42	7.11	95.8	0.26
Townsend Dam, PA	Rainbow	0.139	22.7	3	4.9	15.9	2.87	94.4	0.20
	Rainbow	0.344	22.7	3	4.9	15.9	2.87	86.5	0.19
	Rainbow	0.139	42.5	3	4.9	15.9	2.87	100.0	0.00
Wanapum Dam, WA	Coho	0.154	254.9	5	22.9	8.97	7.24	89.7	0.71
	Coho	0.154	254.9	5	22.9	8.97	7.24	94.9	0.35
	Coho	0.154	311.5	5	22.9	8.97	7.24	92.4	0.58
	Coho	0.154	311.5	5	22.9	8.97	7.24	96.8	0.24
	Coho	0.154	424.8	5	22.9	8.97	7.24	94.8	0.47
	Coho	0.154	424.8	5	22.9	8.97	7.24	100.0	0.00
	Coho	0.154	481.5	5	22.9	8.97	7.24	88.5	1.12
	Coho	0.154	481.5	5	22.9	8.97	7.24	96.8	0.31
West Enfield, ME	At. Salmon	0.212	150.1	3	6.4	9.32	4.88	96.0	0.31
Wilder, NH-VT	At. Salmon	0.191	127.4	5	15.5	11.8	4.57	96.0	0.17

Figure 2 provides a plot of the calculated lambda values for salmonids versus the non-dimensional ratio NL/D. The solid line is a best fit linear relationship, with the equation lambda= -0.8245*(NL/D) + 0.4761. The dashed lines above and below were added to incorporate most of the values. This best fit relationship extends toward negative lambda results for higher NL/D values, which obviously is not possible. Therefore, to establish a reasonable range of probable maximum and minimum lambda values at higher NL/D values it was assumed that if NL/D exceeds 0.335 (NL/D when the relationship results in a lambda of 0.20) then lambda will be assumed to be between a minimum of 0.10 and a maximum of 0.40. The upper range line is parallel and 0.2 higher than the best fit equation, with a minimum value of 0.40 at higher values of NL/D. The lower range line was established by setting lambda equal to 0.20 at

NL/D=0.1, and lambda equal to 0.10 at NL/D=0.335. The equations for the upper and lower range limits are lambda = -0.8245*(NL/D) + 0.6761 and lambda = -0.4258*(NL/D) + 0.2426, respectively (for values of NL/D less than 0.335). For values of NL/D greater than 0.335 the maximum and minimum lambda values were assumed to be 0.4 and 0.1, respectively. A spreadsheet was developed to calculate the lambda values from the existing study results, produce the plot and relationship in Figure 2, and perform the calculations for the survival estimates through the Enloe turbines.

Figure 2: Relationship between Lambda and NL/D for Salmonid Species



Four fish lengths were considered as representative of the range of salmonids that might be present above Enloe Dam (50mm, 100mm, 150 mm, and 250mm). The following calculations were used to develop the probable survival ranges shown in Table 2.

For 50 mm, L=0.05 m and NL/D=0.155. Maximum and minimum lambda values are 0.548 and 0.176, respectively. Entering these lambda values into the mortality equation results in M_{max}=4.29*0.548*0.05=0.118 and M_{min}=4.29*0.176*0.05=0.038, or a survival estimate range of 88.2% to 96.2%. This range is expressed in Table 1 as a probable survival of **92.2% +/- 4.0%**.

For 100 mm, L=0.10 m and NL/D=0.311. Maximum and minimum lambda values are 0.420 and 0.110, respectively. Entering these lambda values into the mortality equation results in M_{max}=4.29*0.420*0.10=0.180 and M_{min}=4.29*0.110*0.10=0.047, or a survival estimate range of 82.0% to 95.3%. This range is expressed in Table 1 as a probable survival of **88.7% +/- 6.6%**.

For 150 mm, L=0.15 m and NL/D=0.466. Maximum and minimum lambda values are 0.40 and 0.10, respectively (since NL/D exceeds 0.335). Entering these lambda values into the mortality equation results in M_{max}=4.29*0.40*0.15=0.257 and M_{min}=4.29*0.10*0.15=0.064, or a survival estimate range of 74.3% to 93.6%. This range is expressed in Table 1 as a probable survival of **84.0% +/- 9.6%**.

For 250 mm, L=0.25 m and NL/D=0.777. Maximum and minimum lambda values are 0.40 and 0.10, respectively (since NL/D exceeds 0.335). Entering these lambda values into the mortality equation results in M_{max}=4.29*0.40*0.25=0.429 and M_{min}=4.29*0.10*0.25=0.107, or a survival estimate range of 57.1% to 89.3%. This range is expressed in Table 1 as a probable survival of **73.2% +/- 16.1%**.

4 REFERENCES

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