US Army Corps of Engineers ®

PHASE II PROJECT APPENDIX

TURBINE OPTIMIZATION FOR PASSAGE OF JUVENILE SALMON AT JOHN DAY DAM

John Day Lock and Dam located on the Columbia River near Rufus, Oregon.

PREPARED BY
U.S. ARMY CORPS OF ENGINEERS
TURBINE SURVIVAL PROGRAM

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EXECUTIVE SUMMARY

This report identifies operating conditions for turbine units at John Day Dam on the Columbia River, where turbine fish passage survival is expected to be higher based on using the tools developed by the Turbine Survival Program (TSP). The 2004 TSP Phase I Report indentified that operating conditions of large Kaplan turbine units appear to have a significant effect on the survival of fish passing through them. This TSP Phase II Project Appendix involves identifying target operating range (TOR) and the targets for project operations.

To reduce strike injuries to fish, the physical geometry of John Day's turbine components was examined. As flow increased, the wicket gates open up and the blade angles steepen. The wicket gates achieve the best alignment with the stay vanes over a 7-degree rotational range from 36 to 43 degrees open. However, the maximum wicket gate opening is often restricted by other constraints such as generator limit.

Additional information to reduce strike frequency, exposure to shear, and turbulent environments came from 1:25 Froude scale model constructed at the Engineering Research and Development Center of a John Day turbine unit. High-speed video of neutrally buoyant beads was taken to assess the strike frequency and severity. The physical model showed that the percentage of beads contacting the stay vanes and wicket gates was low. The lowest number of contacts and direction changes seem to occur for flows larger than 16.0 thousand cubic feet per second (kcfs). In addition, the percentage of beads passing through the gap between the stay vanes and wicket gates appears to increase with flow and be relatively unrelated to the best wicket gate geometry. As with the stay vane region, analysis of beads contacting the runner can give an indication of potential fish injury. In general, contact with the runner was found to decrease with increasing flow rate through the runner. Increasing flow rate of course corresponds to an increase in blade angle and increased open area within the runner environment.

Velocity data was taken at transects near the runner and draft tube exit. Velocity measurements taken near the exit of the draft tube displayed a large difference between the different flow rates tested. The draft tube for John Day turbines has a single vertical splitter wall that divides the draft tube into two equal-sized barrels (designated A and C). Barrel A has a much higher flow rate than barrel C at lower turbine flow rates, but the flow distributes more evenly for flow rates of 16.50 kcfs and higher. Turbulence intensity decreased with increasing flow for both barrels and especially for barrel C. The increased turbulence could cause fish disorientation. While a direct injury or mortality may not result, fish disorientation has the potential to increase vulnerability to predation.

Injury and mortality (barotrauma) can also occur to fish passing through turbines due to exposure to low nadir pressures. An assessment of barotrauma mortality risk for John Day turbines was made using relationships established by laboratory testing, computational fluid dynamics, and field pressure data collected from sensor fish. An equation was generated using the log ratio pressure and tag burden to predict fish mortality. Assuming a 22-foot acclimation depth for salmonids in the John Day forebay, and using existing data and the generated equation, a barotrauma mortality rate without internal tags of 0.62% for 11.80 kcfs (lower 1%) and 6.18% for 20.30 kcfs (upper 1%) was calculated.

Although a number of biological tests have estimated turbine fish passage survival at John Day, they were not designed to provide specific survival estimates at specific operating points. The 2009 Juvenile Salmon Acoustic Telemetry System estimate of survival is 72.8% for subyearling fish and 85.5% for yearling fish. The tag burden for this study was 2.6% for subyearlings and 1.5% for yearlings, which may have resulted in a biased barotrauma injury.

Based on available information, the recommended target operating range for John Day is 15.0 kcfs to 18.80 kcfs at approximately 100 feet of head. This target operating range is consistent with the most open geometry and with bead strike data and draft tube conditions from the physical model, while accounting for the concerns with barotraumas and low nadir pressures at the higher operating discharges.

The TSP team proposes that a thorough turbine survival test be conducted at John Day to establish whether increased survival is seen under the target operating range conditions. Indirect mortality (i.e., predation) is considered to be a large portion of total turbine mortality; therefore, any TST must make the project operating conditions as similar as possible while testing the different unit operating conditions.

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Acronyms and Abbreviations

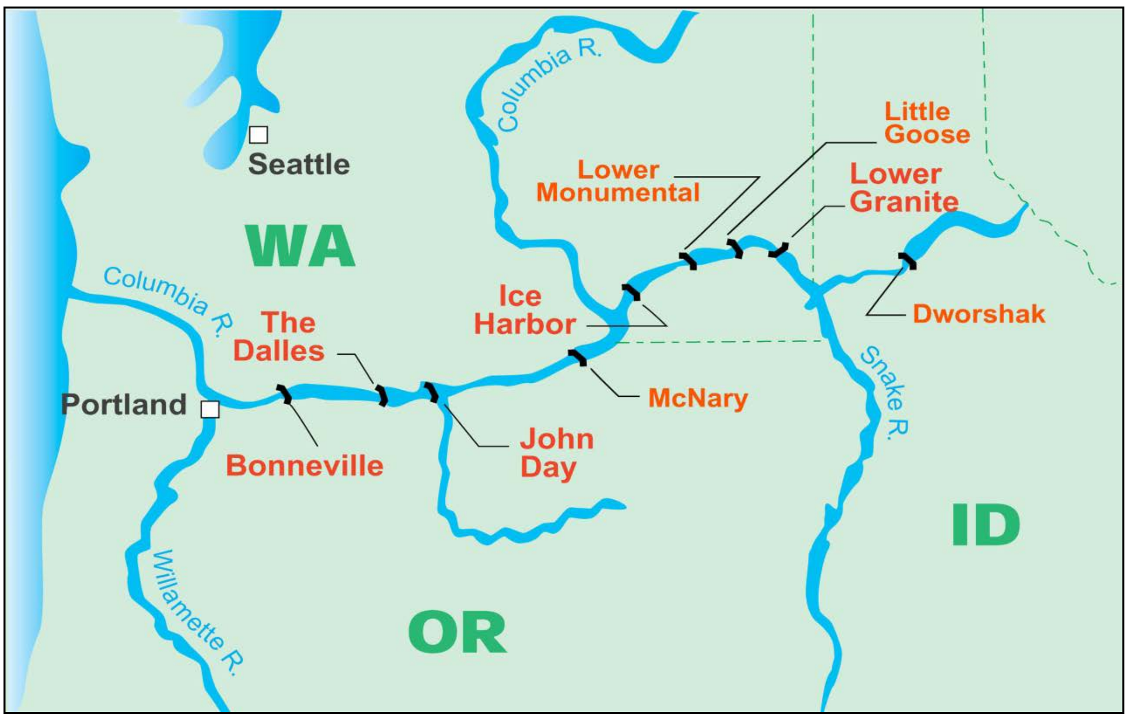
BiOp	Biological Opinion
BLH	Baldwin-Lima-Hamilton (turbine manufacturer)
CFD	computational fluid dynamics
cfs	cubic feet per second
CI	confidence interval
CRFM	Columbia River Fish Mitigation
ERDC	Engineering Research and Development Center
FPE	fish passage efficiency
FPP	Fish Passage Plan
ft	feet (foot)
JBS	juvenile bypass system
kcfs	thousand feet per second
LDV	Laser Doppler Velocimeter
msl	mean sea level
MW	megawatt(s)
NOAA	National Oceanic and Atmospheric Administration
psia	pounds per square inch absolute
RM	river mile
SPE	spill passage efficiency
STS	submerged traveling screen
TOR	target operating range
TSP	Turbine Survival Program
TST	turbine survival testing
TSW	top spillway weir(s)
USACE	U.S. Army Corps of Engineers
VBS	vertical barrier screen

1. INTRODUCTION

The Turbine Survival Program (TSP) is part of the U.S. Army Corps of Engineers' (USACE) multi-faceted Columbia River Fish Mitigation (CRFM) program. The first phase of the TSP involved developing tools to evaluate the physical conditions fish experience as they pass through large Kaplan turbines typical of USACE projects. The TSP Phase I Report (USACE 2004a) indentified that the operating conditions of the large Kaplan turbine units appear to have a significant effect on survival of fish passing through them. Phase II of the TSP involves turbine survival testing (or biological index testing) at USACE facilities. This report identifies operating conditions for John Day turbines where turbine fish passage survival is expected to be higher based on the utilization of the tools developed by the TSP program.

John Day Dam is the third hydroelectric project from the mouth of the Columbia River located at river mile (RM) 216 (Figure 1). The dam crosses the river near Rufus, Oregon, about 25 miles upstream from The Dalles and just below the mouth of the John Day River. Lake Umatilla, impounded by the John Day Dam, extends about 76 miles up to McNary Dam.

Figure 1. Location of John Day Lock and Dam



The John Day powerhouse has 16 turbine units; fish by-pass screens are installed in each of the turbine unit intakes. Although these screens are effective in intercepting the majority of the juvenile steelhead, a significant percentage of juvenile fish continue to pass through the turbines. Survival estimates for radio-tagged fish passing the John Day turbines are among the lowest observed within the Federal Columbia River Power System. Turbine survival estimates (route-specific survival model of Skalski et al. 2002) for yearling and subyearling Chinook salmon ranged from 71.9% to 83.2% in 2002 and 2003 (Counihan et al. 2003a, b). Turbine survival estimates for Columbia and Snake River dams more commonly fall within the 85% to 95% range (USACE 2004b). The need to improve survival through John Day turbines is clear and the possibility for improving survival exists while specifying operations that are realistic.

Results of multiple field and laboratory studies indicate that improved survival through the John Day turbines may be achieved by changing the operating conditions for the existing turbines. These include balloon tag and telemetry tag survival studies, sensor fish pressure and acceleration measurements of the turbine flow path, laboratory pressure investigations, and physical hydraulic model investigations. Results from these studies indicate restricting the operating zone currently defined by within ± 1% of peak efficiency may improve fish passage survival. This report summarizes results from the various studies and presents information to support the recommendation to conduct a field test for verification of an improved operating range for safer fish passage.

1.1. Project Description

Completed in 1971, the John Day Project includes a powerhouse, spillway, navigation lock, and fish passage facilities (Figure 2 and Figure 3). The structure is primarily a concrete gravity dam with a north abutment embankment section.

Figure 2. John Day Powerhouse, South Fish Ladder, and Juvenile Fish Bypass System

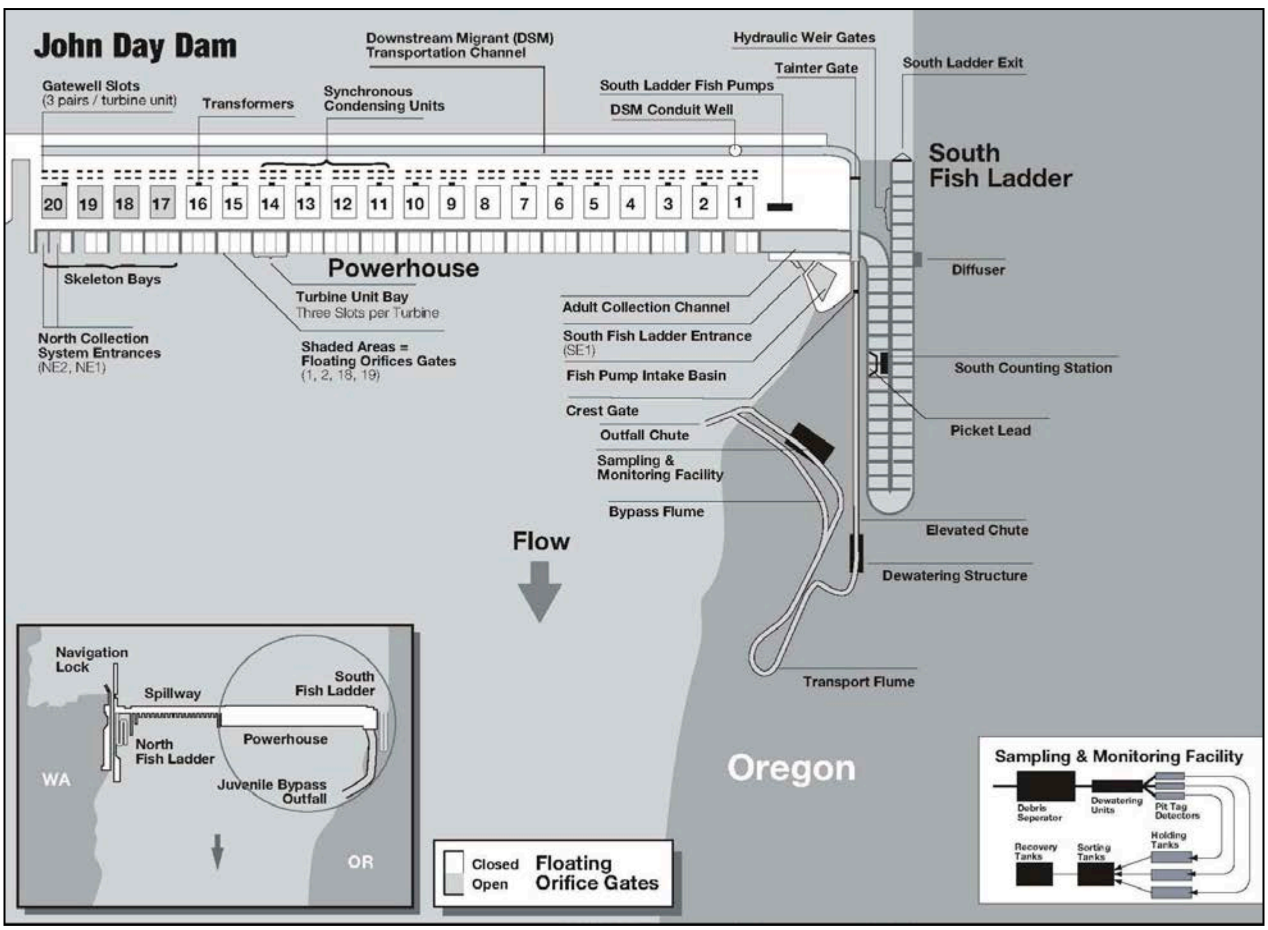
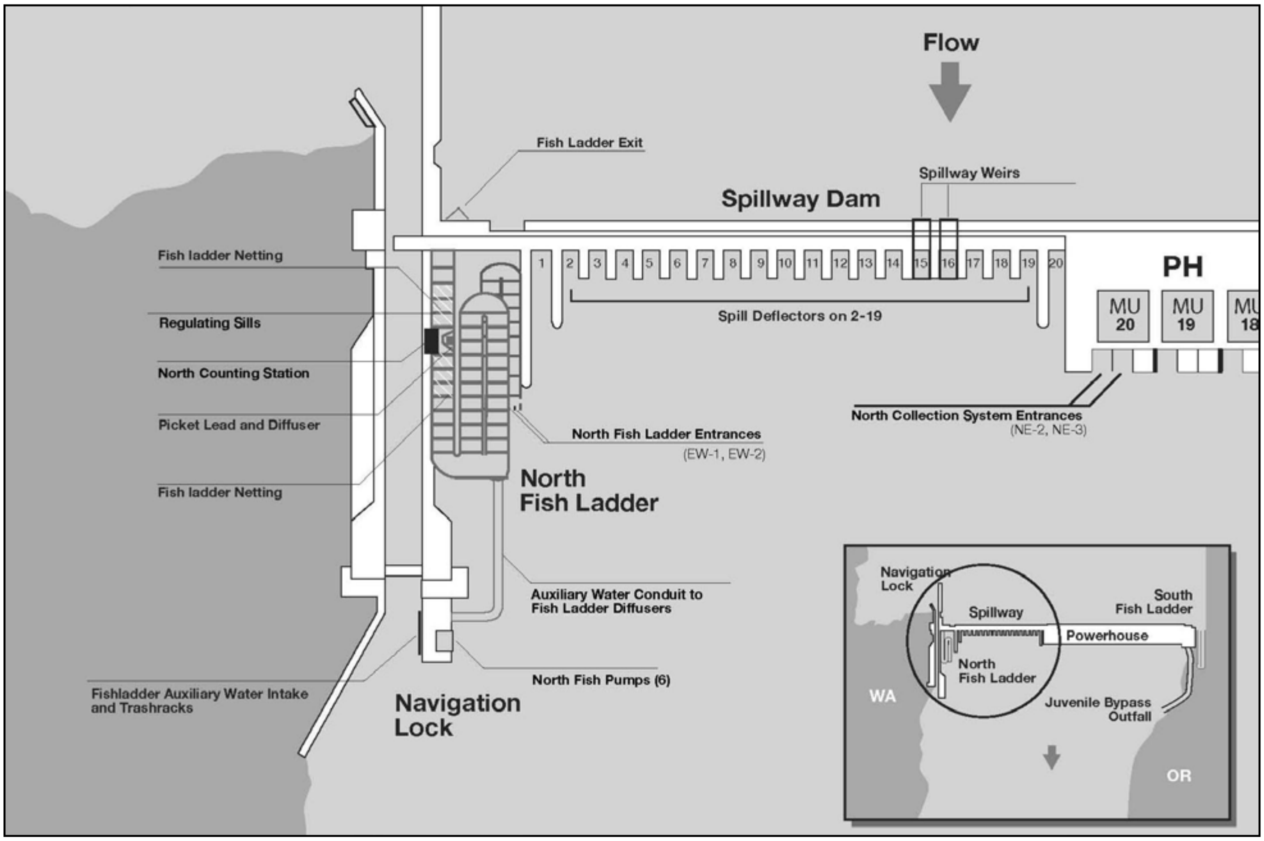


Figure 3. John Day Dam Spillway, Navigation Lock, and North Fish Ladder



The powerhouse is 1,975-feet long and contains 16 Baldwin-Lima-Hamilton (BLH) turbines of 155 megawatts (MW) each, for a total generating capacity of 2,480 MW. All turbines are Kaplan, six-blade units operating at 90 revolutions per minute. The last of the 16 generators went on line in November 1971. The north end of the powerhouse has four skeleton bays providing a potential expansion of four additional turbines. There is a history of linkage problems for the BLH turbines. Several turbine units have blades presently welded in a fixed position.

The spillway is located adjacent to the powerhouse and abuts the navigation lock on the Washington shore. It has twenty 50-foot wide spillway bays each capable of discharging up to 50,000 cubic feet per second (cfs) under normal pool elevations. In a flood event, the total spillway discharge capacity is approximately 2,250,000 cfs.

Fish passage facilities include two adult fish ladders and a screened juvenile bypass system (JBS). The north fish ladder has two main entrances located adjacent to spillway bay 1 and exits upstream along the Washington shore. The south fish ladder has three main entrances, one at the south end of the powerhouse and two smaller entrances at its north end. Ten floating orifice-type entrances also are distributed across the downstream powerhouse face. The south fish ladder exits upstream adjacent to the Oregon shore.

The JBS at John Day has undergone several modifications in the last 25 years. Currently, each main unit intake has a 20-foot submersible traveling screen that diverts approximately 200 cfs of flow up into a dewatering gate slot. A vertical barrier screen (VBS) located between the dewatering gate slot and the operating gate slot removes all but 14 cfs of this flow. The remaining 14 cfs of water and guided fish are discharged through a 14-inch orifice into a collection channel, and eventually released approximately 600 feet downstream of the powerhouse through an outfall adjacent to the Oregon shore. The JBS also includes a juvenile smolt monitoring facility that was put into operation in 2000.

1.2. PROJECT OPERATIONS

1.2.1. General Project Operations

John Day is a storage project and the dam can be manipulated to provide flood risk management for the lower river. The normal operating pool elevation during fish passage season (April 1 through November 30) typically fluctuates from elevation 262 to 265 feet mean sea level (msl). The operating range varies from elevation 257 to 268 feet msl.

A strict operating plan is used for John Day to maintain acceptable tailrace conditions for downstream migrant fish. As the total river flow increases, the amount of discharge released from the powerhouse must increase relative to the spillway discharge. If the powerhouse discharge is too high, a large eddy forms downstream of the spillway, which results in a large percentage of the flow returning into the stilling basin. If the spillway discharge is too high, a large eddy is formed downstream of the powerhouse. As a result of these conditions, spillway and powerhouse operations are coordinated to provide hydraulic conditions deemed optimal for egress of migrating salmonids through the tailrace.

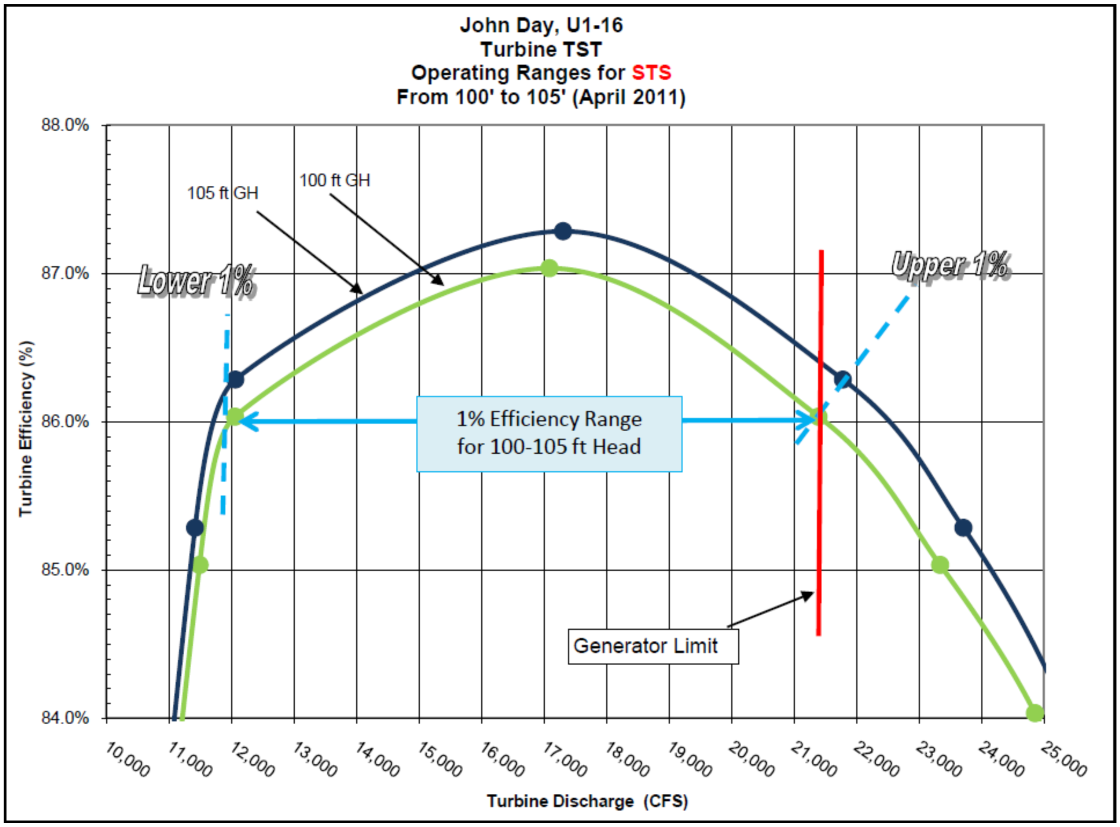
Flow distribution and operational guidelines for John Day, as described in the National Oceanic and Atmospheric Administration (NOAA) Fisheries Biological Opinion (BiOp) and in the annual Fish Passage Plan (FPP) developed by the USACE Northwestern Division, are based upon many different factors that affect juvenile and adult passage at the dam. Requirements include seasonal operation, turbine unit restrictions for tailrace patterns, turbine unit operation priority, turbine operation within 1% of peak efficiency, minimum and maximum turbine operation, Bonneville Power Administration power requirements, spillway gate operation pattern, scheduled maintenance, unplanned outages, and others. All of these factors play a role in the operation of John Day in consideration of juvenile and adult fish migration. These factors are not variables within the context of this study and are assumed to be a part of project operation. The current FPP is the approved method of operating John Day.

1.2.2. Turbine Operations

The John Day turbines are operated within 1% of the best efficiency in accordance with the FPP, which implements requirements of the NOAA Fisheries BiOp (2000, 2004, 2008). The FPP is updated annually. The approach of restricting turbine operations was formalized in the 2000 BiOp, which requires turbine operations be limited to ± 1% of best operating efficiency. The basis for this rule resulted from research reported by Bell (1981) and Eicher Associates (1987).

A review of turbine survival study results and the 1% operating range was completed by Bickford and Skalski (2000). It was found that highest direct survival did not occur at the best operating efficiency and that direct passage survival did tend to exhibit a curvilinear relationship with increasing turbine discharge. Direct turbine passage survival tests were normally limited to turbine operations within ± 1% of best operating range, highest survival was often found to occur within the 1% operating range but not always. It cannot be concluded that highest direct turbine survival occurs within 1% of best operating efficiency. Highest direct turbine survival for some turbine units may well occur at untested turbine operations outside the 1% operating range. The peak efficiency and the 1% operating range are dependent on both the head on the turbine and the flow through the turbine. The John Day turbine efficiency vs. flow curves, with the submerged traveling screen (STS) installed, are shown in Figure 4. The 1% operating range is defined by a ±1% drop from peak efficiency for the head at which the turbine is operated. Compared with a number of projects, John Day has a very wide 1% operating range and for most heads, the upper 1% limit is above or near the generator limit.

Figure 4. John Day Turbine Efficiency Curves with STS Installed



The JDA turbines were designed for a head range of 100 to 105 feet with an optimum design head of 102 feet. The forebay continues to operate at the original design of 260 to 268 feet msl as described in John Day's Water Control Manual.

The FPP specifies turbine unit operating priority as shown below. The FPP also requires spill during much of the fish passage season, which influences the powerhouse tailrace egress conditions. Details of the operational requirements for John Day can be found in the FPP (USACE 2012). The spill requirements are for alternating 30% and 40% spill with the top spillway weirs (TSWs) from early April through July 20. Late summer spill through August 31st the spill requirements are 30% spill with TSWs. It can be seen that for the majority of the time during fish passage season, the TSWs are installed; therefore, this should be consider the current baseline turbine unit priority.

- Fish passage season without TSWs: Units 1-4 in any order, then units 5-16 in any order.
- Fish passage season with TSWs: Units 5, 1, 3, 16, 14, 12, 10, 8, 15, 2, 11, 7, 4, 13, 9, 6.

2. DEFINE TARGET OPERATING RANGE FOR TURBINES

There are many different pieces of information that help to estimate the target operating range (TOR) for fish passage survival through John Day turbines. First, the physical geometry of different operating conditions will be considered. Second, physical modeling data of different operating conditions that was guided by the physical geometry will be discussed. Pressure information for John Day comes from both a computational fluid dynamics (CFD) model and a sensor fish study. This information, in conjunction with laboratory studies, gives an indication of the potential for pressure injuries at different operating conditions. While no turbine-specific biological field studies have been performed to date, the project survival studies and some data correlation will be discussed. Finally, this information will be tied together to provide an estimate of a target operating range for John Day turbines.

2.1. PHYSICAL GEOMETRY CONSIDERATIONS

As discussed in Section 3.2 of the Phase II Main Report, there is a potential to reduce injury and direct mortality of migrating salmon passing through turbines by operating at a more open geometry. Wittinger and others (2010) indicate that a good geometric relationship is often not found within the existing 1% operating limits. For John Day, well-aligned stay vanes and wicket gates occur over a 7-degree rotational range from 36 to 43 degrees open. However, the maximum wicket gate opening is often restricted by other constraints such as generator limit. The runner blade angle can vary from 19 to 36 degrees. Open geometry blade angles would be considered the top of this range, but these are also restricted by other constraints.

The geometry for turbine operation (runner blade position and wicket gate position) is represented in a family of curves called an "on-cam diagram." For example, Figure 5 illustrates a family of on-cam curves over the head range of 90 to 105 feet at John Day. Some of the units have broken blade mechanisms and have the blade angle fixed at 29 degrees. Superimposed on the curves is a horizontal line drawn at fixed 29-degree blade angle illustrating the effect of a Kaplan turbine runner operating at a single blade position. Over the operating head range, the wicket gate position corresponding to that blade angle varies from about 37 to 41.5 degrees. The best wicket gate geometric alignment is about 41 degrees open.

To better illustrate the best geometric wicket gate opening range, sketches were prepared from a graphical three-dimensional computer model of the John Day design to show the wicket opening in relation to the stay vanes. Figure 6 shows the minimum wicket gate opening beginning to shadow the stay vane at 36 degrees open. Figure 7 shows an interim wicket gate opening of 38 degrees open, and Figure 8 shows the best overall wicket gate opening of 41 degrees considering the entire arrangement of the wicket gate and stay vanes.

Figure 9 shows the best geometric operating range of the wicket gates for heads between 100 to 105 feet. The operating range of the wicket gates is about 5 degrees of rotation. The positions show a very good geometric relationship while maintaining a reasonable total flow capability with limited operational flexibility.

Figure 5. Cam Curves and Wicket Gate Operating Range

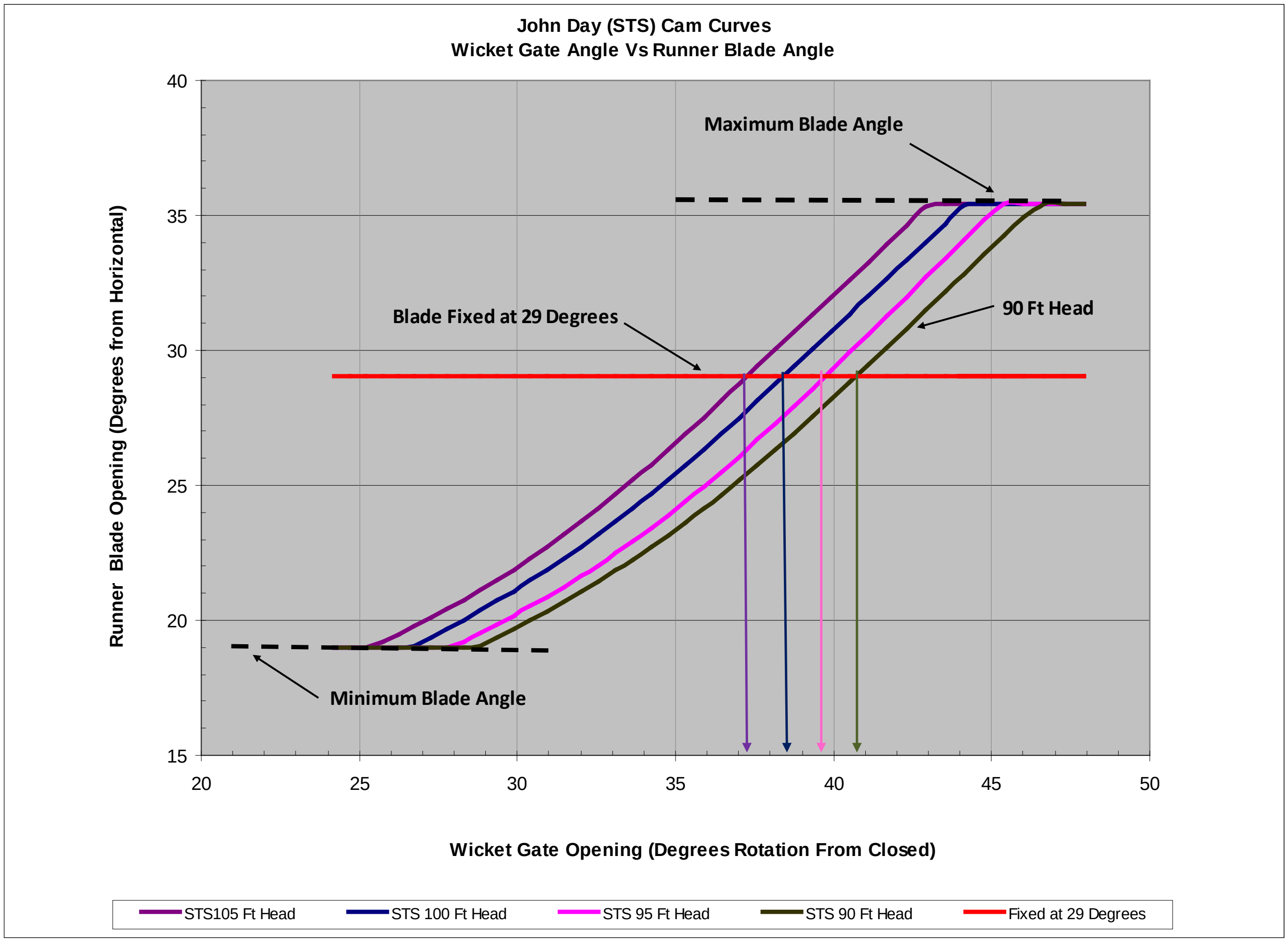


Figure 6. Wicket Gate at 36 Degrees

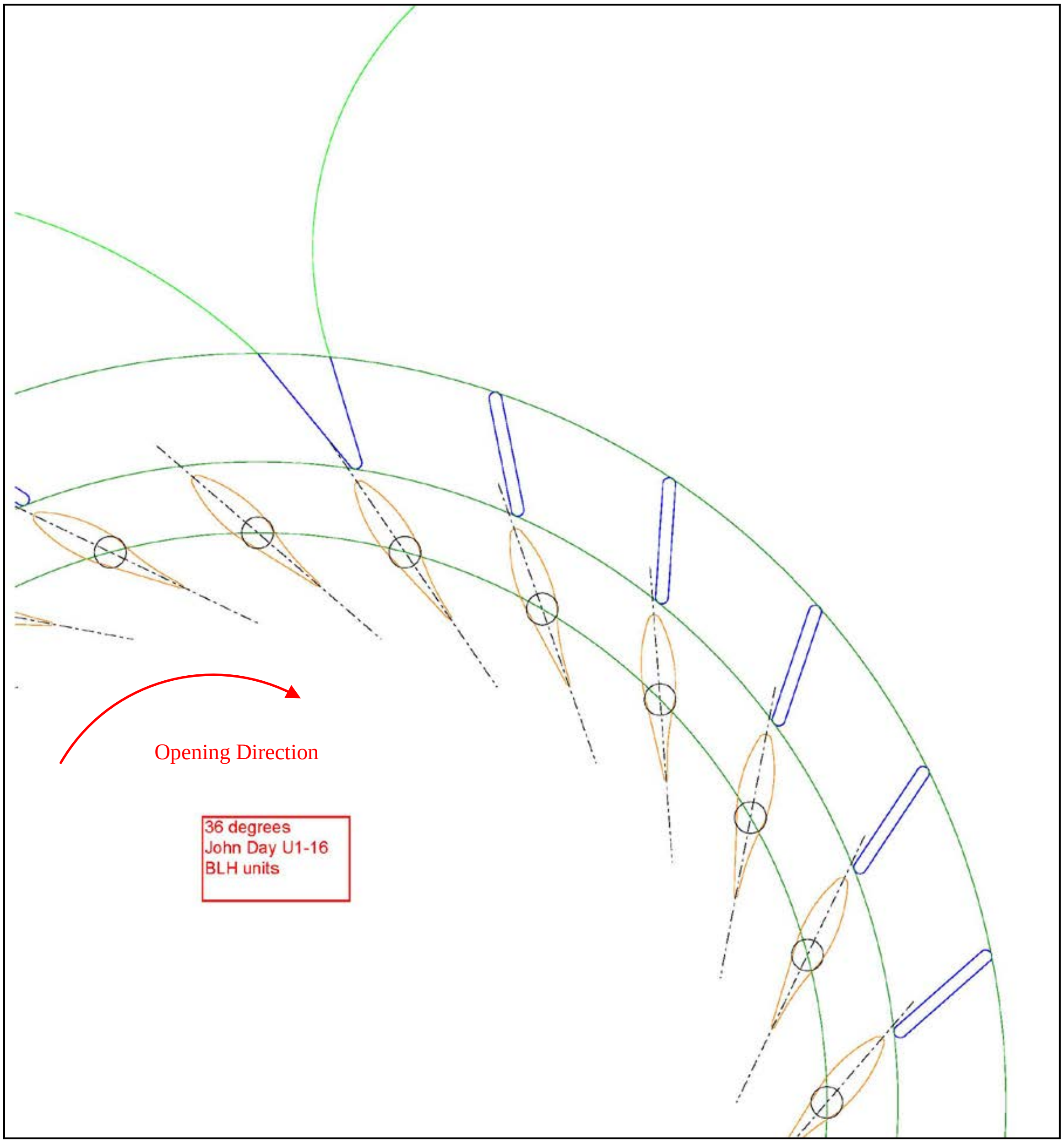


Figure 7. Wicket Gate at 38 Degrees

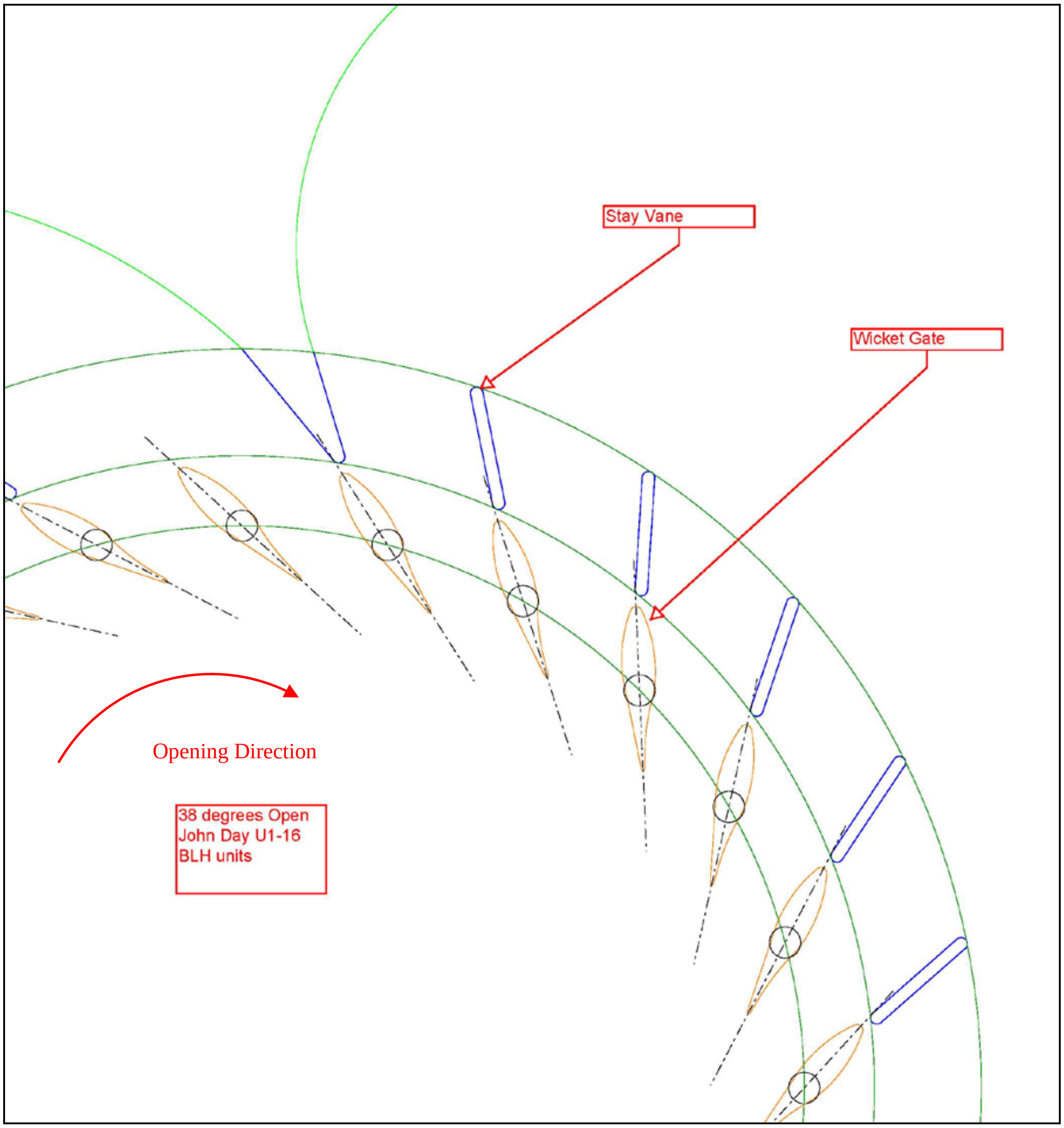


Figure 8. Wicket Gate at Best Geometric Opening of 41 Degrees

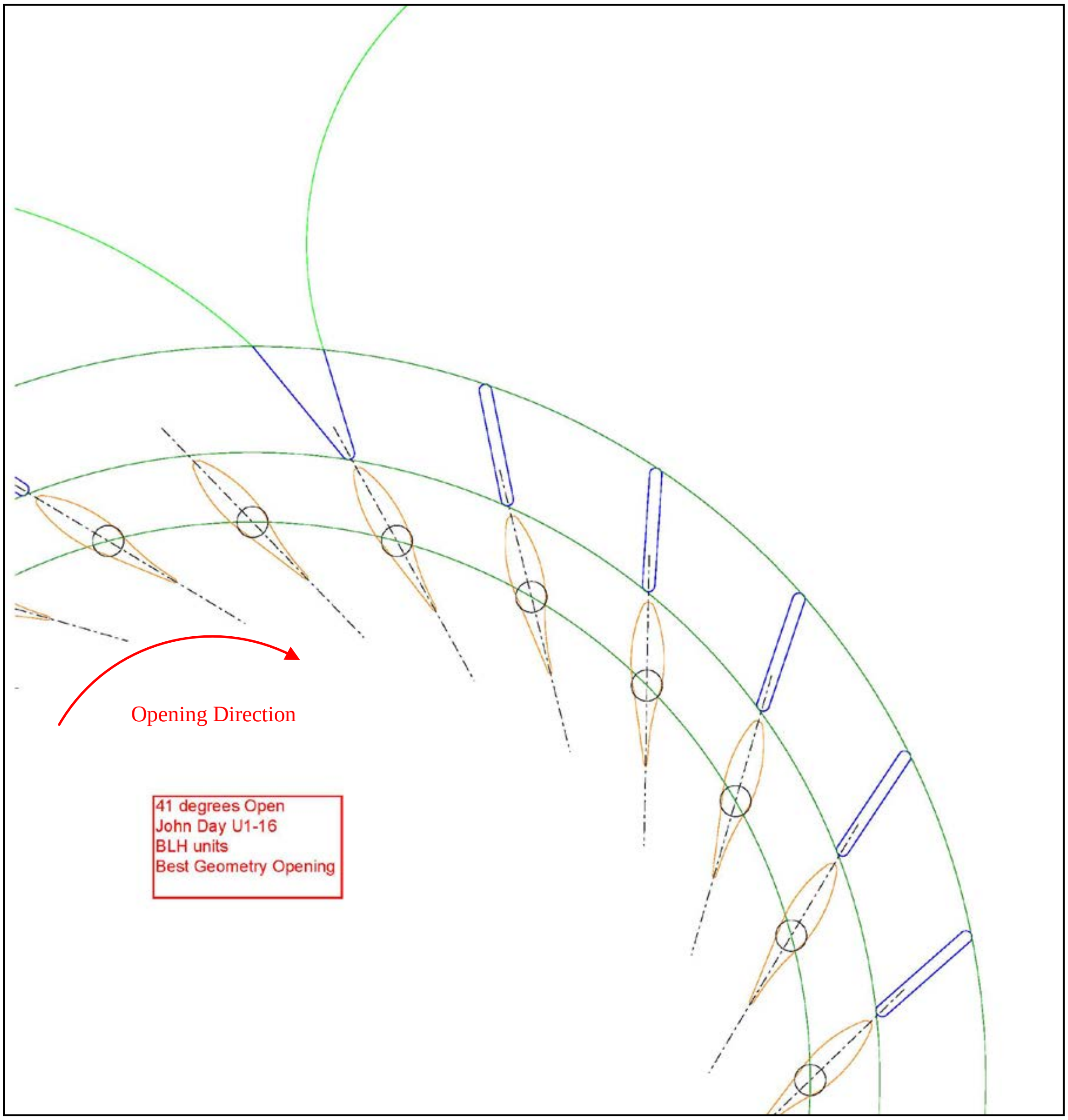
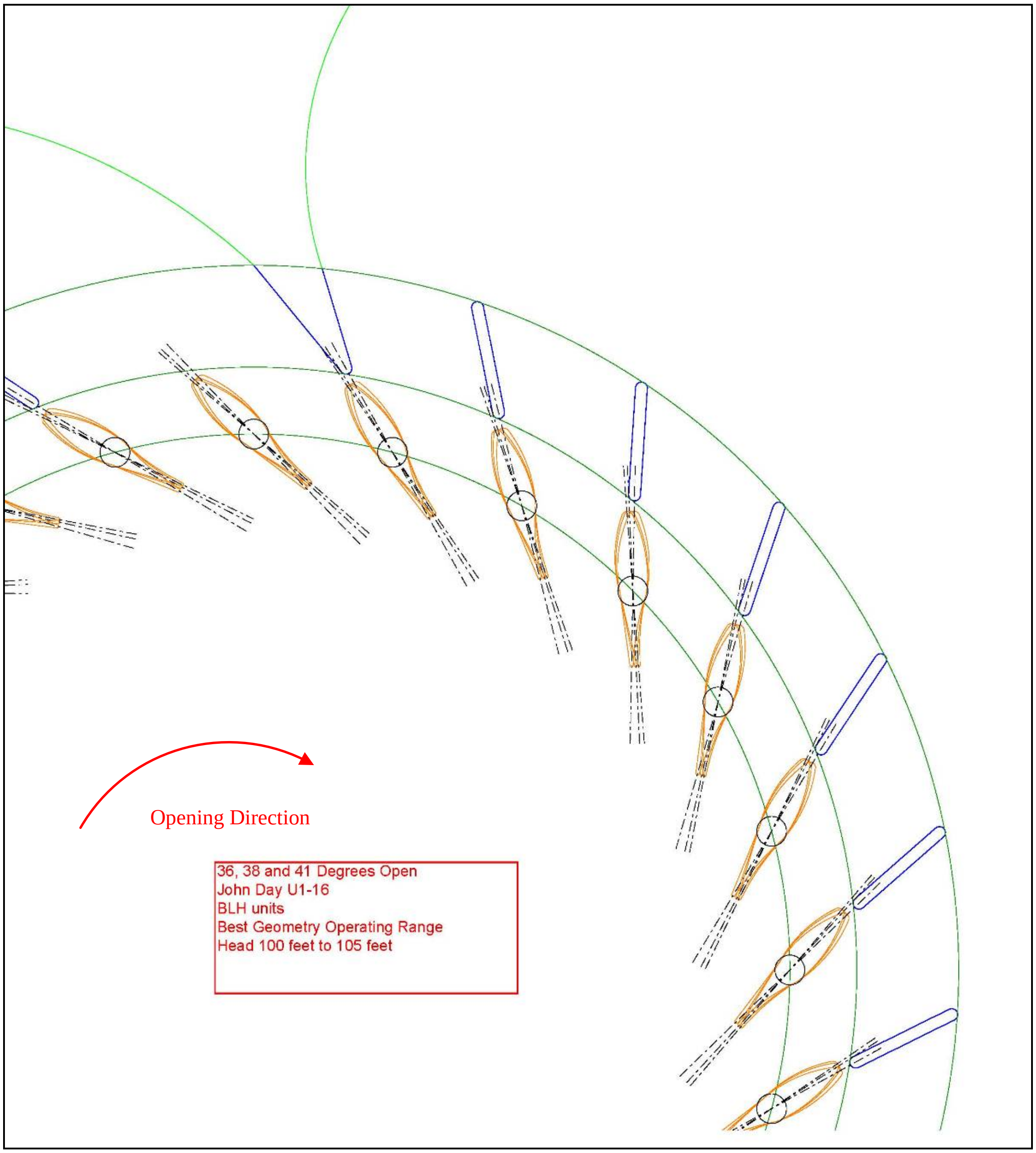


Figure 9. Best Geometry Wicket Gate Operating Range



When operated as a Kaplan, the wicket gate operating range for best geometry is 36 to 43 degrees. However, other constraints such as head, generator power limit, cavitation limit and 1% operating limit restrict operation. Considering these constraints, the normal operating range is 36 to 41 degrees open. A turbine operating zone of best geometry is defined to allow flexibility in turbine and powerhouse operation. The normal operating head range is typically between 100 to 105 feet with 102 feet being the average. The best geometric operating range for turbine survival testing (TST) will be limited to being between these two heads.

To illustrate the effect of wicket gate position on turbine geometric operation, a family of "on-cam" curves was prepared for John Day. Figure 10 represents wicket gate and runner blade geometric relationship for a range of 90 to 105 feet head. Overlaid on this graph are generator limit, 1% limits and best operating point for each head. The shaded area (red) is the zone (100 to 105 feet head) of best geometric operation of a John Day turbine.

Figure 10. Best Geometry Operating Range

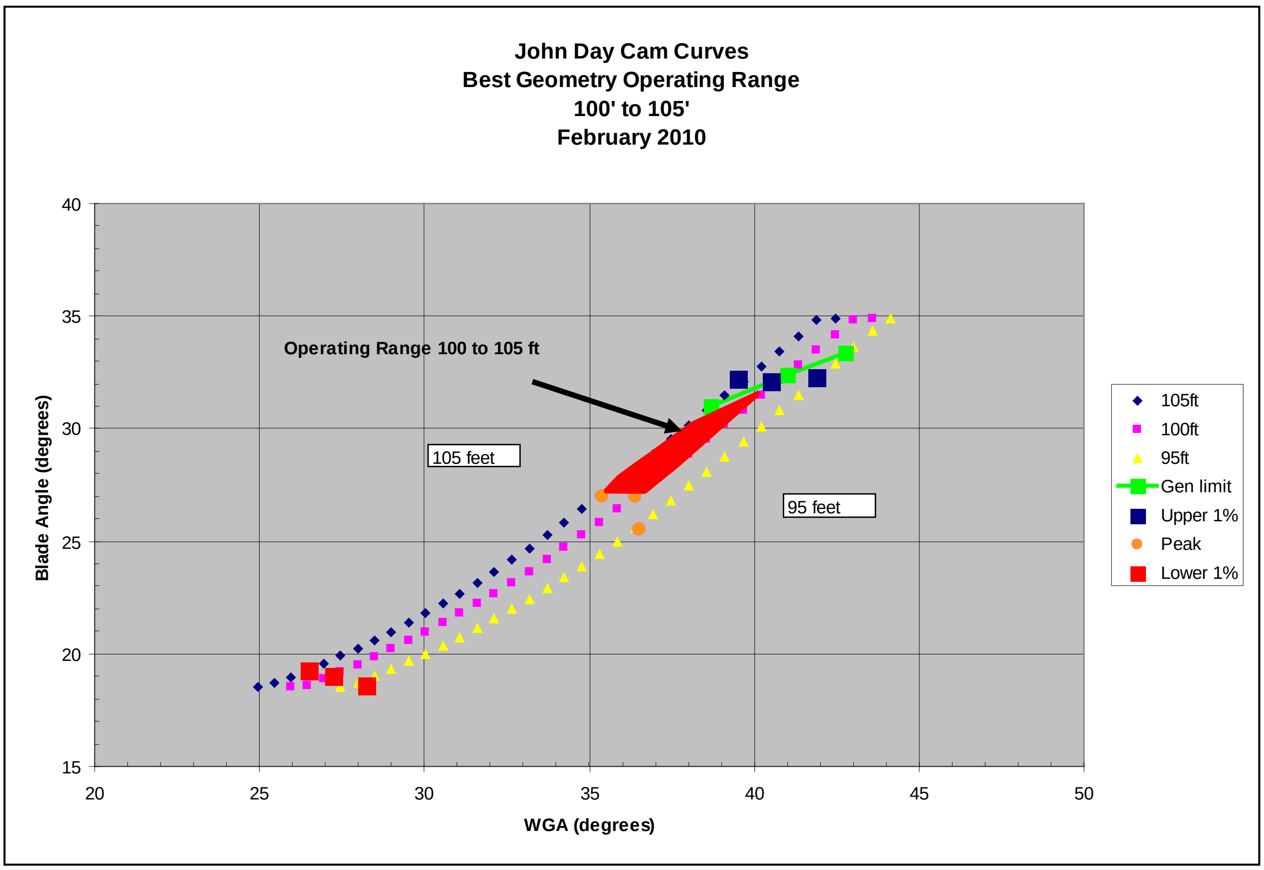


Figure 10 shows the zone of best turbine operating geometry for John Day; however, this information is difficult to relate to existing operating parameters such as power and wicket gate servomotor percent open. To better illustrate the turbine-operating zone based on power, Figure 11 was prepared. This figure overlays the best geometric zone of turbine operation on the turbine performance curves of 100 to 105 feet of head with the various operational constraints identified.

Figure 11. Turbine Best Geometry Operating Power Range

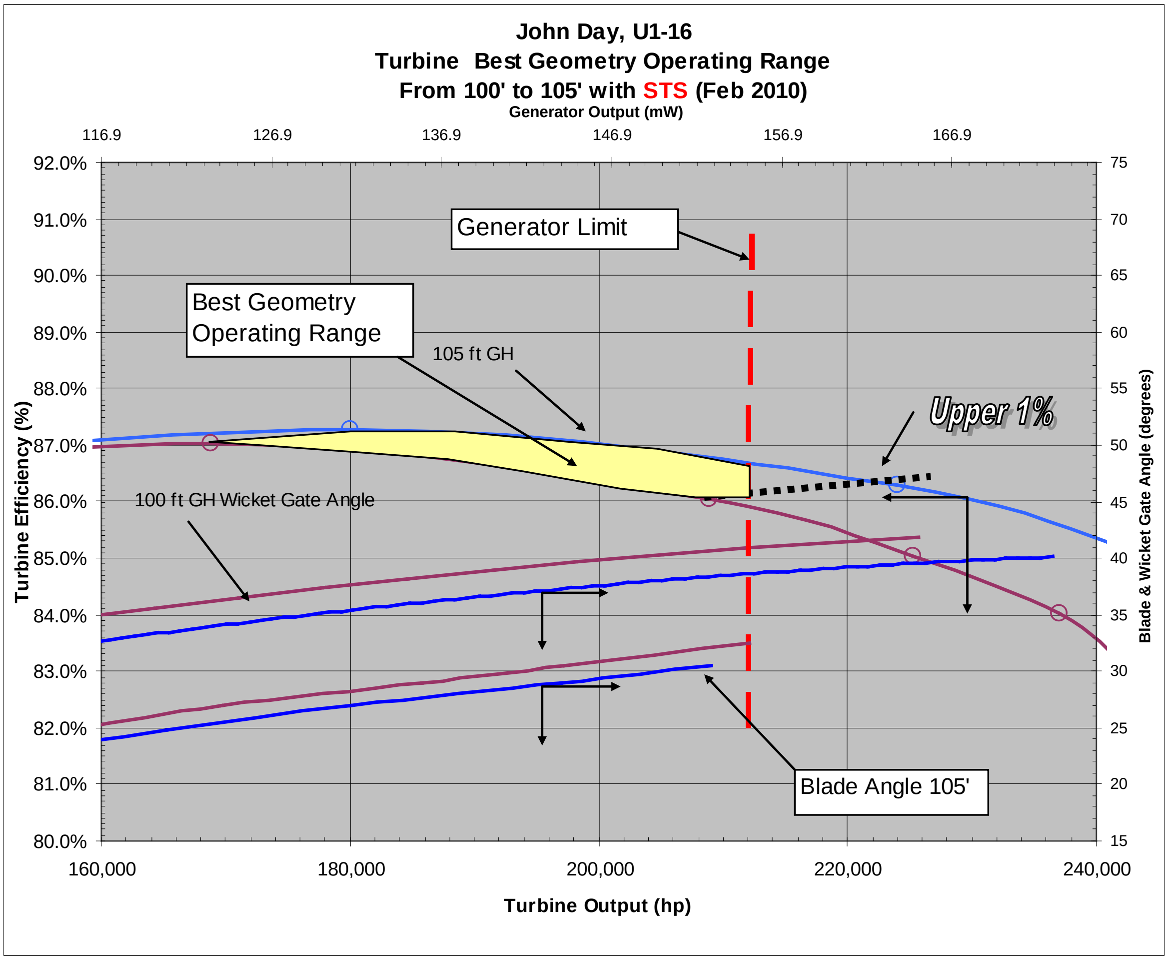


Table 1 shows the operating conditions (for on-cam operation) over the target geometry range and at best geometry for wicket gate alignment.

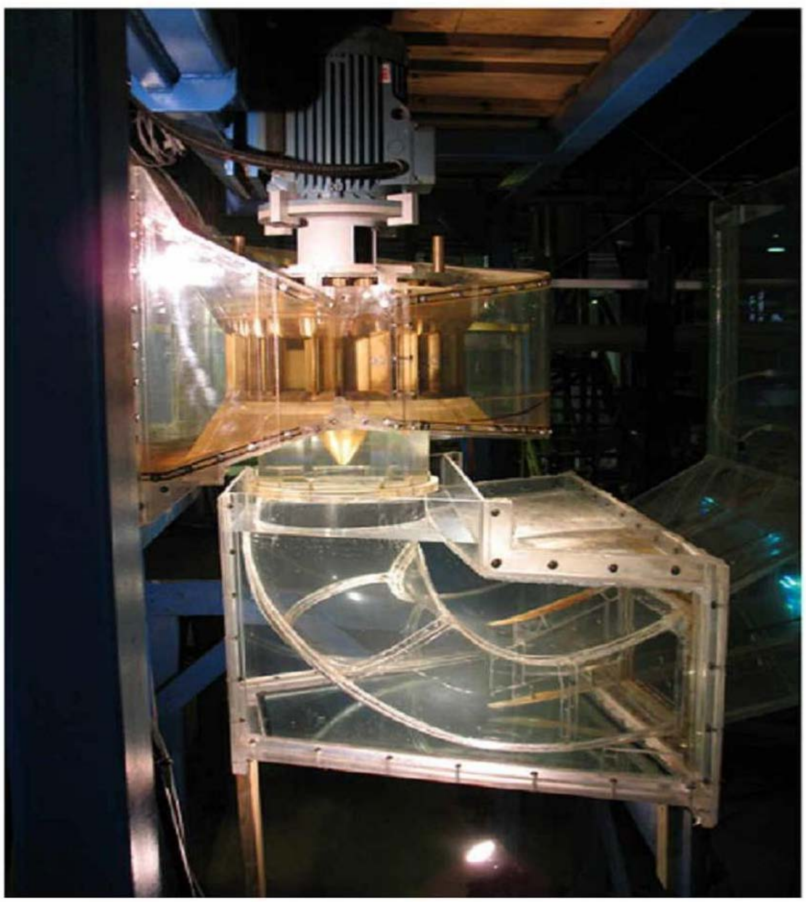
Table 1. Best Wicket Gate Geometry for John Day at 95 feet of head

Parameter	Best Geometry	Best Geometry Range	
		Lower	Upper
Wicket Gate Angle – degrees open	41.0	36	43
Blade Angle – degrees open	31.5	26.2	33.6
Power – horsepower (hp)	200,500	155,800	212,400
Flow – thousand cubic feet per second (kcfs)	21.70	16.70	23.10
Efficiency – %	85.70%	86.4%	85.1%

2.2. PHYSICAL OBSERVATIONAL MODEL INFORMATION

The John Day physical turbine model is a 1:25 Froude-based scale model of a single turbine unit constructed at the Engineering Research and Development Center (ERDC) in Vicksburg, MS (Figure 12). The model replicates 800 feet of approach, each of the three intake bays, the scroll case, the distributor including all adjustable wicket gates and stay vanes, the six-bladed Kaplan turbine runner, the draft tube, and 400 feet of downstream topography. The model was used to evaluate the hydraulic condition within the turbine and the potential impact of variable turbine operations on fish. The evaluation included the release of dye into the turbine flow path to observe general flow patterns, extensive velocity measurements using a Laser Doppler Velocimeter (LDV) and high-speed imaging of neutrally buoyant beads released into the flow path.

Figure 12. John Day 1:25 Physical Model Turbine and Draft Tube



The prototype flow rates investigated were approximately 11.80 thousand cubic feet per second (kcfs), 16.30 kcfs, 18.60 kcfs, and 19.90 kcfs for the runner operated as Kaplan. These correspond to approximately lower 1%, between peak and lower 1%, and two points between peak and upper 1%. Prior to pinning some blades in the field, additional tests were conducted at the lower 1%, peak and upper 1% for the runner operated as a propeller at a fixed-blade angle of 29 degrees. These tests were performed approximately at the average project head of 102 feet (prototype scale) with the STS installed.

Neutrally buoyant beads were introduced at various points within the intake. High-speed video was then used to determine potential shear and strike injury by observing indications of bead contacts and severe change in directions (those that did not follow the general flow direction). It was proven through a study at McNary Dam that fish do not behave as passive particles within an intake at 7.0 kcfs and 12.0 kcfs through a turbine (Carlson 2002). However, the passive particle hypothesis is an assumption that must be made without solid alternative information, although this assumption may be valid for passage within the runner due to the high velocities. Release points were found that corresponded to passage at the runner hub and the runner blade tip. Without adequate information on fish distribution, an equal distribution within the runner was assumed. Therefore, all the bead passage data was averaged together for information presented in this appendix.

The first major area that presents a chance of strike injury is in the vicinity of the stay vanes and wicket gates. High-speed video was used to analyze the percentage of beads that had a severe contacts and change in direction while passing either the stay vanes or wicket gates (Figure 13). The physical model showed that the percentage of beads contacting these structures was much more constant across the operating range than the change in direction. Additionally, the lowest number of direction changes seemed to occur for flows larger than 16.0 kcfs. The percentage of beads passing through the gap between the stay vanes and wicket gates were also analyzed using the high-speed video (Figure 14). Unlike the contacts and direction changes, this percentage appears to increase with flow and be relatively unrelated to the best wicket gate geometry; however, the percentages at all operating points is still very low.

Figure 13. Severe Bead Contacts and Direction Changes at Stay Vanes and Wicket Gates

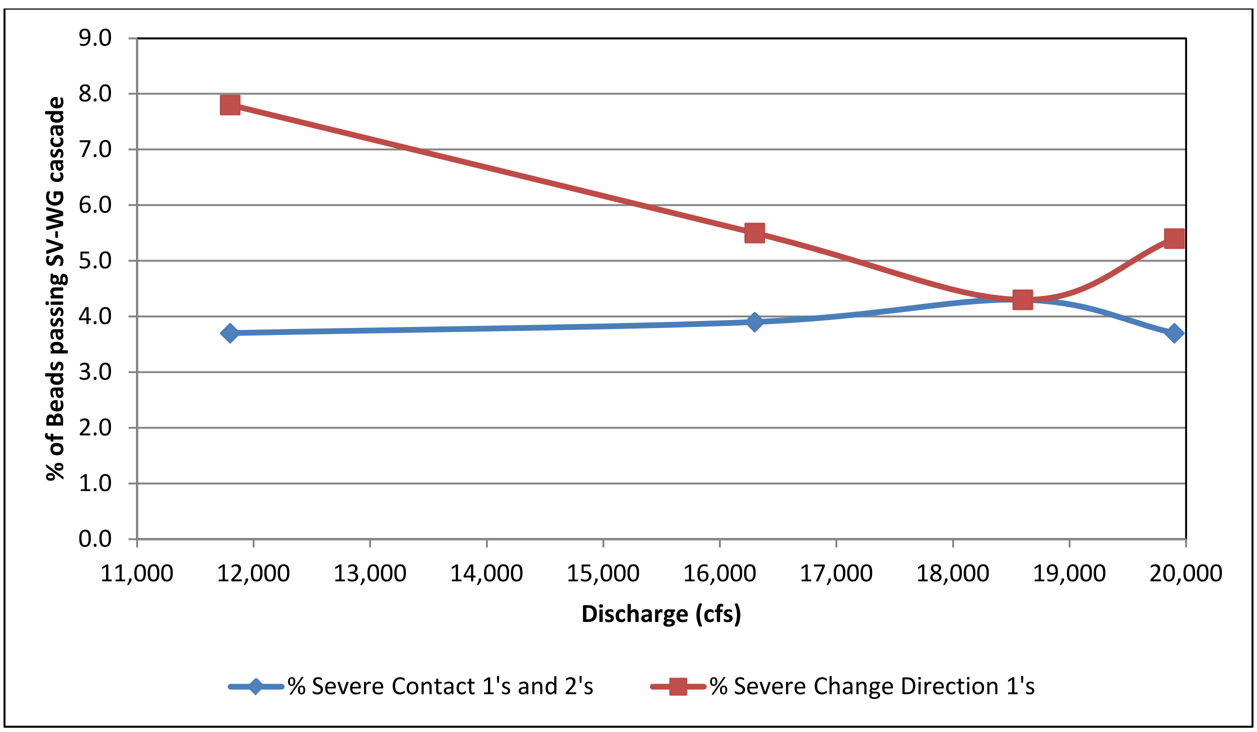
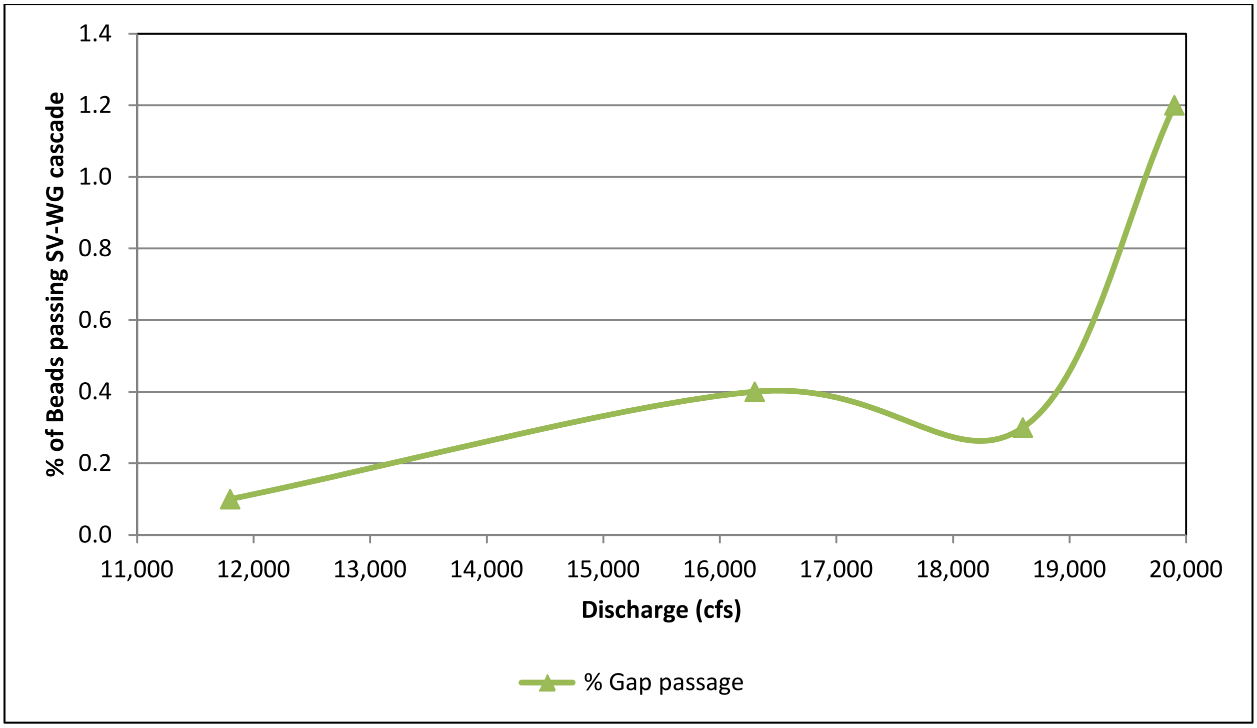
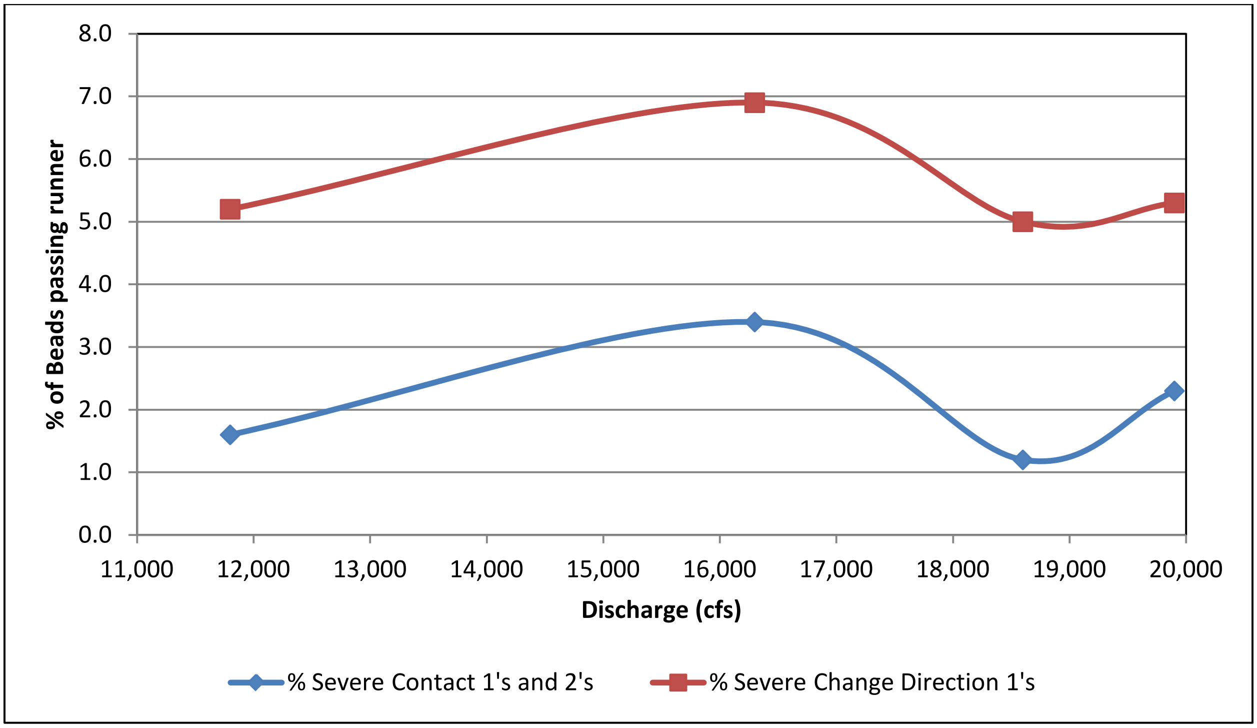


Figure 14. Beads Passing Through Gap between Stay Vanes and Wicket Gates



The next area for potential mechanical injury for fish is passing the runner blades of the turbine. As with the stay vane region, analysis of beads contacting the runner can give us an indication of potential injury. In general, Figure 15 shows that contact and direction change within the runner decreases with increasing flow rate through the runner but surprisingly the lower 1% has low numbers. Increasing flow rate of course corresponds to an increase in blade angle and increased open area within the runner environment.

Figure 15. Severe Bead Contacts and Direction Change within Runner



In addition to the bead analysis, velocity measurements were made at multiple transects using a LDV. The draft tube exit is one area that displayed a large difference between the tested flow rates as determined by velocity measurements. The draft tube for the John Day turbine units has a single vertical splitter wall which divides the draft tube into two barrels (designated A and C) of equal cross-sectional area and length. The velocities at the draft tube exit were used to estimate the flow rate through each of these barrels. Barrel A has a much higher flow rate than barrel C at the lower turbine flows, but the flow distributes more evenly for flow rates of 16.30 kcfs and higher (Figure 16). Relating the average barrel velocity with individual velocity measurements, turbulence intensity is a measure of variability within the draft tube. Data indicates that turbulence intensity decreases with increasing flow for both barrels, but particularly in barrel C (Figure 17). This also corresponds to a qualitative observation of a large vortex existing below the runner at the lower 1% that disappears at higher discharges. Results shown in these two figures relate to the fact that the draft tubes were designed to pass the highest design flows; thus, the full flow area is not fully utilized at lower flow rates resulting in areas of recirculation. The increased turbulence at the lower flow rates could cause fish disorientation. While a direct injury or mortality may not result, the disorientation has the potential to increase vulnerability to predation.

Figure 16. Flow Percent Passing Through Each Draft Tube

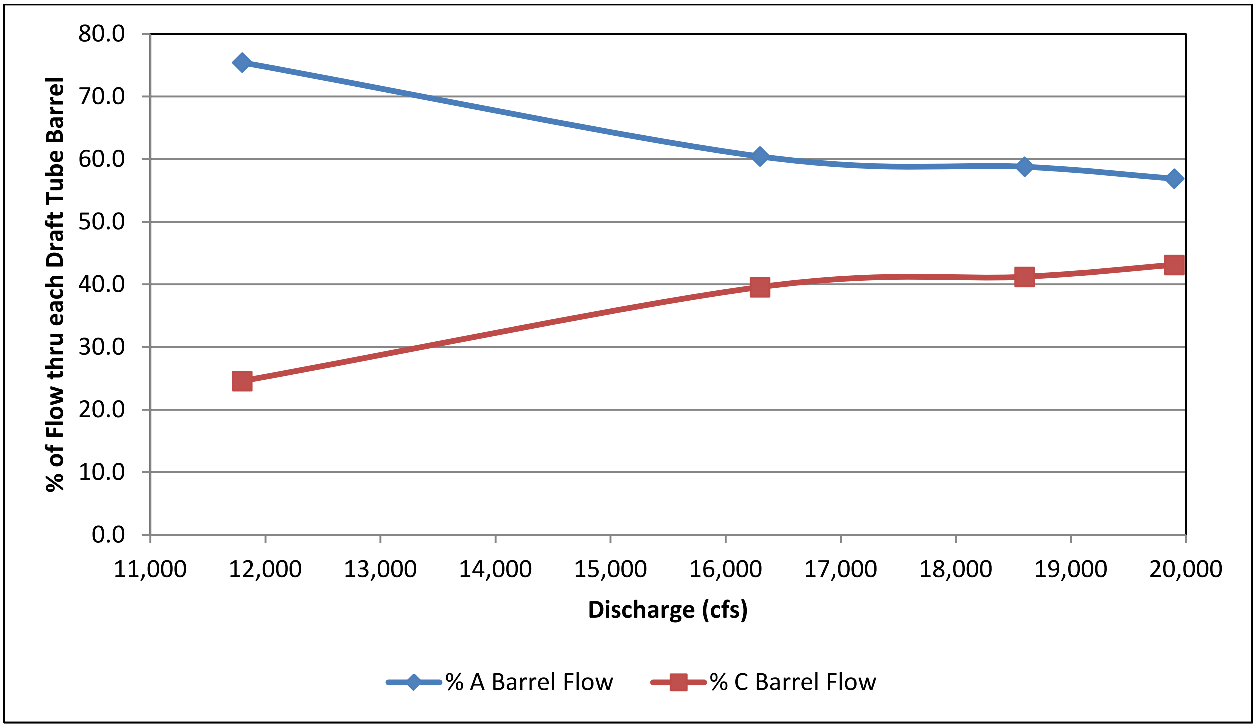
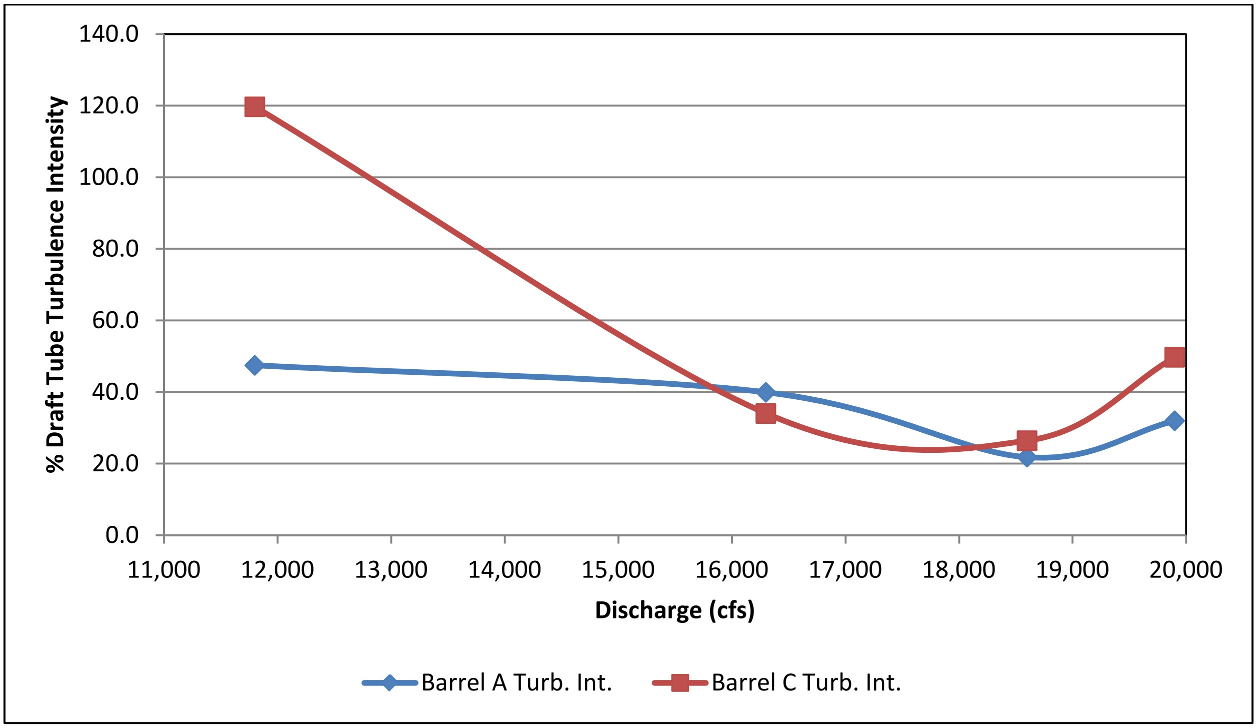


Figure 17. Turbulence Intensity for Draft Tube Barrels



Based on physical model information, flow rates above 16.30 kcfs (slightly above peak efficiency) show improved hydraulic conditions over flow rates below 16.30 kcfs. There is some improvement in draft tube conditions for flow rates higher than 16.30 kcfs and additionally the best operating point for runner passage is the 18.60 kcfs or 29 degree on-cam operating point. It would be expected that mechanical and shear related injuries would reduce between peak efficiency and the 18.60 kcfs operating point (compared to operating at the low end of the operating range). For both the distributor and the runner the collected model information shows an increase in bead contact and direction change above the 18.60 kcfs operating point. While the increase is not significant for the runner passage, this points to little fish passage benefit for increasing discharge significantly above the 18.60 kcfs operating point.

2.3. PRESSURE INFORMATION FROM LABORATORY AND FIELD DATA

An assessment of barotrauma mortality risk for John Day turbines were made using relationships established with laboratory testing (see Section 3.4 in the Phase II Main Report), field pressure data collected with sensor fish, and CFD information. To apply this laboratory data to fish passage at John Day for run-of-river fish, the acclimation pressure and the nadir pressure are needed. There is minimal information for the acclimation pressure for fish entering the John Day turbines; however, the nadir pressure for three operating points has been identified using sensor fish (Figure 18). Computational fluid dynamics has also been used to define the nadir pressure for the same three operating points (Figures 18 and 19). The CFD results and descriptions of the methods used for generating a nadir distribution are discussed in the 2011 Electric Power Research Institute-Department of Energy conference proceedings (Kiel and Ebner 2011).

Figure 18. Sensor Fish and CFD Data for John Day

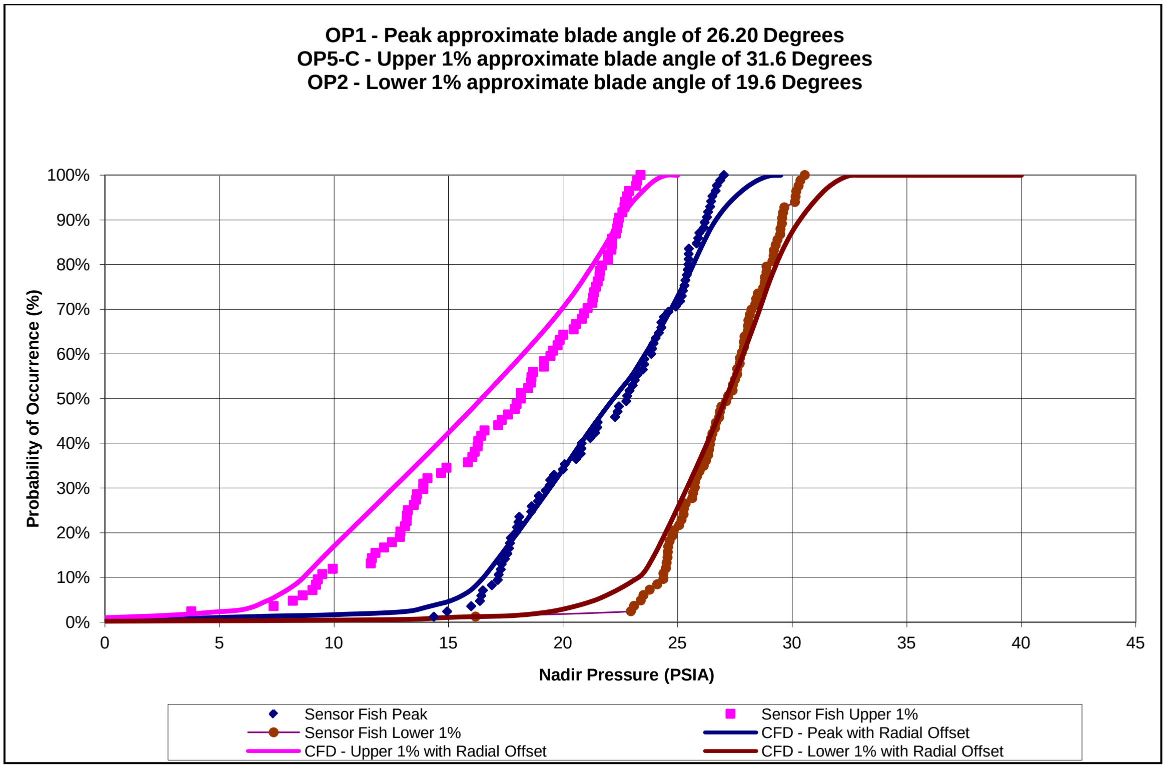
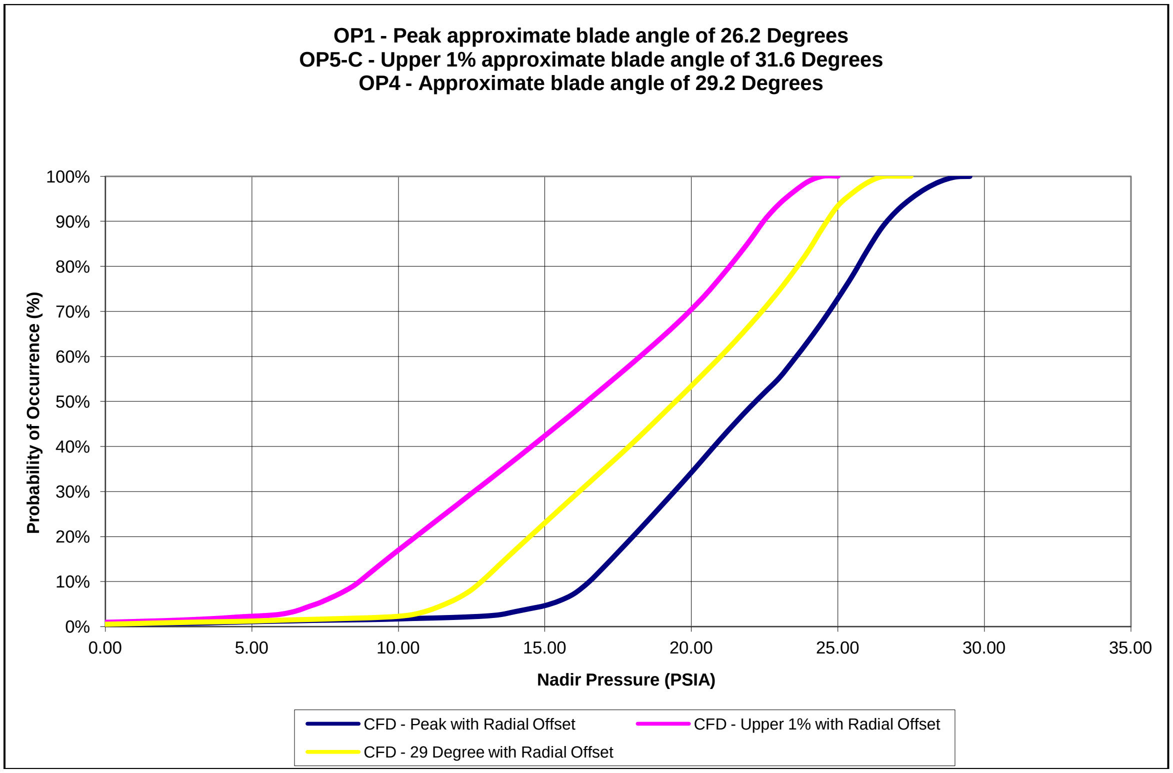


Figure 19. CFD Data for John Day



In addition, nadir and acclimation pressures need to be determined to estimate the mortality rate for untagged juvenile Chinook salmon using Equation 2 (see Section 3.4 in the Phase II Main Report). Since little is known about acclimation depth of juvenile salmon approaching turbines, four acclimation depth (or pressures) are shown in Table 2. For the purposes of this report, a predicted maximum acclimation depth of 22 feet (Pflugrath et al. 2012) will be used to compare predicted barotrauma mortality rates at different operating conditions with those from other sources. The predicted pressure related mortal injury varies significantly across the distribution of nadir pressures that fish acclimated to a distribution of depths may experience. Additional methods are to utilize the full nadir distribution generated by the CFD by determining probabilities for different nadir bins, as well as the acclimation distribution; however, for the purposes of this appendix, the single maximum acclimation depth of 22 feet will be utilized.

Table 2. Calculated Mortality at John Day (using Equation 2)

Parameter	Nadir Pressures (psia)	Calculated Fish Mortality for Lower 1% Operating Condition			
		0 ft Water Acclimation	10 ft Water Acclimation	22 ft Water Acclimation	25 ft Depth Acclimation
Mean Nadir	22.19	0.08%	0.21%	0.54%	0.66%
Minimum Nadir	0.73	99.75%	99.91%	99.96%	99.97%
Maximum Nadir	30.55	0.02%	0.06%	0.16%	0.19%
		Calculated Fish Mortality for Peak Operating Condition			
Mean Nadir	21.97	0.08%	0.22%	0.56%	0.68%
Minimum Nadir	14.36	0.42%	1.13%	2.81%	3.41%
Maximum Nadir	27.02	0.04%	0.10%	0.25%	0.31%
		Calculated Fish Mortality for Upper 1% Operating Condition			
Mean Nadir	16.08	0.27%	0.73%	1.83%	2.23%
Minimum Nadir	0.125	100.00%	100.00%	100.00%	100.00%
Maximum Nadir	22.87	0.07%	0.19%	0.48%	0.58%

Table 3 shows the results using the risk assessment method. It is interesting to compare the results of the risk assessment method to the single point method in that for the same acclimation depth, the predicted mortality is greater than using the median nadir pressure but certainly less than using the minimum nadir pressure, which appears to indicate that the calculated mortality by this method is heavily influenced by the high mortality rate of the less frequent low nadirs. Due to uncertainties for both the acclimation exposure, the magnitude of the difference between the operating conditions cannot be predicted. However, the direct mortality due to decompression is most likely higher at higher flow rates and the risk assessment mortality estimates at 22 feet of acclimation will be used, which likely slightly overestimates the mortality rate.

Table 3. Calculated Mortality at 22 feet Acclimation Using Risk Assessment Method

Turbine Passage Condition	Turbine Discharge (kcfs)	Calculated Mortality (%)
Lower 1%	11.80	0.62%
Peak	16.50	1.81%
Upper 1%	20.30	6.18%

2.4. BIOLOGICAL FIELD STUDY INFORMATION

The John Day Configuration and Operation Plan (USACE 2007) describes project passage distribution and survival for the various passage routes at John Day. Tables 3-2, 3-3 and 3-4 in the plan are replicated here as Tables 4, 5 and 6. Turbine survival has not been correlated to turbine operating condition.

Table 4. Estimated Passage Distribution and Survival for Yearling Chinook Salmon

Year	Spill Treatment % spill day/night	Spillway		Juvenile Bypass		Turbine		Dam Passage Survival
		Passage	Survival	Passage	Survival	Passage	Survival	
1999	12-hr 0/45	52.6	---	29.9	---	17.5	---	---
	24-hr 30/45	65.6	---	21.9	---	12.5	---	---
2000	12-hr 0/53	75.1	98.6 (92.5, 104.7)[a]	14.6	---	10.3	---	97.6 (90.9, 104.3)[a]
	24-hr 30/53	85.8	93.7 (87.6, 99.8)[a]	6.0	---	8.2	---	93.5 (87.8, 99.2)[a]
2001	12-hr 0/30	---	---	---	93.2 (89.0, 97.4)[a]	---	---	---
2002	12-hr 0/54	48.1	99.3 (95.8, 103.0)	36.0	91.1 (85.7, 95.9)[a]	15.9	77.8 (67.3, 87.0)	92.9 (89.5, 96.3)
	24-hr 30/30	53.1	100.0 (96.5, 104.0)	26.7	99.1 (94.0, 103.0)[a]	20.2	83.2 (74.4, 90.9)	96.3 (93.0, 99.6)
2003	12-hr 0/60	56.7	93.4 (90.0, 96.3)	29.0	101.9 (99.6, 103.6)	14.3	89.1 (82.9, 95.3)[b]	92.2 (87.5, 96.9)
	12-hr 0/45	47.4	93.9 (90.3, 96.7)	36.2	98.8 (95.9, 100.8)	16.4	80.7 (77.2, 84.2)[c]	94.0 (89.9, 98.1)

Passage distribution is the percentage of all study fish passing JDA. The 95% confidence intervals (CI) are in parentheses. Survival estimated using the route-specific survival model, unless otherwise noted.
[a] Survival estimated using the paired release-recapture model.
[b] Estimated turbine survival for fish released directly into turbine intake during the day/no spillway operations.
[c] Estimated turbine survival for fish released directly into the turbine intake at night during 45% spill.

Table 5. Estimated Passage Distribution and Survival for Subyearling Chinook Salmon

Year	Spill Treatment % spill day/night	Spillway		Juvenile Bypass		Turbine		Dam Passage Survival
		Passage	Survival	Passage	Survival	Passage	Survival	
1999	12-hr 0/25	44.0	---	---	---	---	---	---
	12-hr 0/51	50.0	---	---	---	---	---	---
	24-hr 28/51	78.0	---	---	---	---	---	---
	24-hr 21/25	58.0	---	---	---	---	---	---
2000	12-hr 0/59	53.9	---	24.8	---	21.3	---	---
	24-hr 30/59	81.5	---	9.6	---	8.9	---	---
2001	24-hr 0/0	---	---	---	86.8 (78.4, 95.2)[a]	---	---	---
2002	12-hr 0/54	41.7	98.5 (93.4, 102.3)	28.9	---	29.4	86.6 (79.5, 92.8)[b]	92.8 (88.5, 97.1)
	24-hr 30/30	57.1	100.3 (98.3, 107.8)	13.1	---	29.8	96.6 (88.5, 103.1)[b]	99.2 (94.1, 104.3)
2003	12-hr 0/60	48.1	90.1 (87.7, 92.2)	22.6	89.2 (85.5, 92.4)	29.3	71.9 (67.1, 76.4)	84.5 (81.4, 87.6)
	24-hr 30/30	61.7	95.5 (93.8, 97.0)	13.1	92.1 (87.7, 95.5)	25.2	72.2 (67.3, 76.7)	88.6 (85.6, 91.6)

Passage distribution is the percentage of all study fish passing the project. The 95% confidence intervals (CI) are in parentheses. Survival estimated using the route-specific survival model, unless otherwise noted.
[a] Survival estimated using the paired release-recapture model.
[b] Estimate represents total powerhouse passage survival (turbine- and JBS-passed fish combined).

Table 6. Estimated Passage Distribution and Survival for Juvenile Steelhead

Year	Spill Treatment % spill day/night	Spillway		Juvenile Bypass		Turbine		Dam Passage Survival
		Passage	Survival	Passage	Survival	Passage	Survival	
1999	12-hr 0/45	44.9	---	49.3	---	5.8	---	---
	24-hr 30/45	52.6	---	37.8	---	9.6	---	---
2000	12-hr 0/53	68.8	98.8 (96.1, 101.5)[a]	24.2[d]	---	7.0[d]	---	95.7 (91.6, 99.8)[d]
	24-hr 30/53	76.0	90.5 (84.0, 97.0)[a]	15.3[d]	---	8.7[d]	---	90.4 (83.7, 97.1)[d]
2001	12-hr 0/30	---	---	---	91.7 (87.7, 95.7)[a]	---	---	---
2002	12-hr 0/54	57.2	95.8 (89.9, 100.0)	28.0	88.2 (82.2, 94.2)[b]	14.8	93.0 (84.7, 99.5)[c]	94.0 (88.7, 99.3)
	24-hr 30/30	55.3	93.2 (85.7, 98.8)	34.6	92.6 (85.9, 99.3)[b]	10.1	89.9 (80.7, 96.7)[c]	91.5 (86.2, 96.8)

Passage distribution is the percentage of all study fish passing the project. The 95% confidence intervals (CI) are in parentheses. Survival estimated using the route-specific survival model, unless otherwise noted.
[a] Survival estimated using the paired release-recapture model.
[b] Estimated survival for fish released directly into the JBS during night spill operations.
[c] Estimated total powerhouse passage survival (turbine- and JBS-passed fish combined due to lower numbers of fish passing either route).
[d] Estimated passage efficiency through turbines and the JBS were calculated using the spill passage efficiency (SPE) and fish passage efficiency (FPE) estimates (FPE-SPE = JBS passage and 1-FPE = turbine passage).

Normandeau and Skalski (2007) conducted a study of turbine survival of juvenile hatchery Chinook (total length = 117-183 millimeters) at John Day Dam in 2006. Fish were balloon tagged and released directly into the A, B, and C intake bays of unit 9 and turbines were operated at the lower 1%, peak, and upper 1% range (Table 7). Recapture rates were high ranging from 96.1% to 99.4%. The lowest 48-hour survival (93%; 95% CI = 89.3% to 96.7%) was observed in the B intake at peak efficiency, and highest 48-hour survival (98%; 95% CI = 95.9% to 100.1%) was observed in the A intake at the lower 1% (Table 7). Control fish were released in the tailrace with 100% survival.

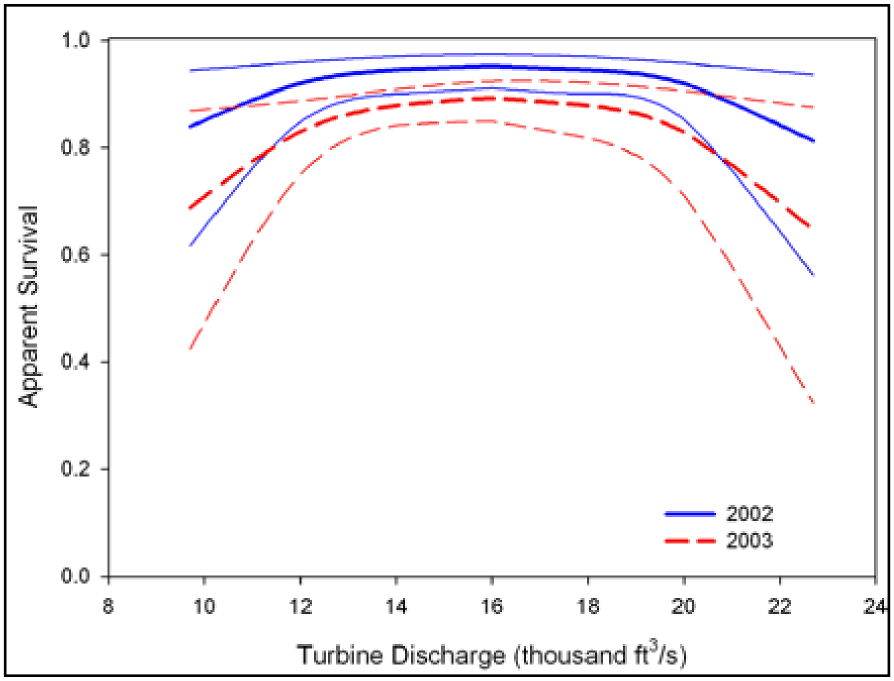
Table 7. Juvenile Chinook Turbine Survival for John Day within 1% Operating Range

Intake Bays	Lower 1% Efficiency (11.8 kcfs)	Peak Efficiency (16.6 kcfs)	Upper 1% Efficiency (best geometry) (19.9 kcfs)
Slot A	0.979 (0.011)	0.939 (0.020)	0.977 (0.013)
Slot B	0.931 (0.019)	0.930 (0.019)	0.940 (0.019)
Slot C	0.935 (0.020)	0.932 (0.020)	0.959 (0.015)

*Survival estimates presented with standard error in parenthesis.
Source: Normandeau and Skalski 2007.

In 2010, the U.S. Geological Survey was contracted by the USACE to conduct an analysis of data from previous radio or acoustic tagged juvenile salmonids passing through John Day turbines (Beeman et al. 2011). Passage survival data at John Day from 2002 and 2003 was pooled and associated with environmental and operating conditions at time of passage. A relationship between turbine passage survival and water temperature was found for both yearling and subyearling Chinook. It is possible that water temperature could affect the acclimation depth of turbine passed fish and therefore, could affect the barotrauma mortality rate. Additionally, a quadratic relationship of subyearling Chinook survival relative to turbine unit discharge was found (Figure 20). No relationship was found for yearling Chinook. It can be noticed that the peak of the survival curve is very broad and difficult to differentiate. The areas of the graphs that do exhibit lower survival are based on very few operating points; therefore, this might not be the correct fit for the data. While this analysis was an important step, the results of the analysis indicate that a targeted turbine survival test might better define the effect of turbine unit discharge on survival.

Figure 20. John Day Turbine Unit Effect for Subyearling Chinook

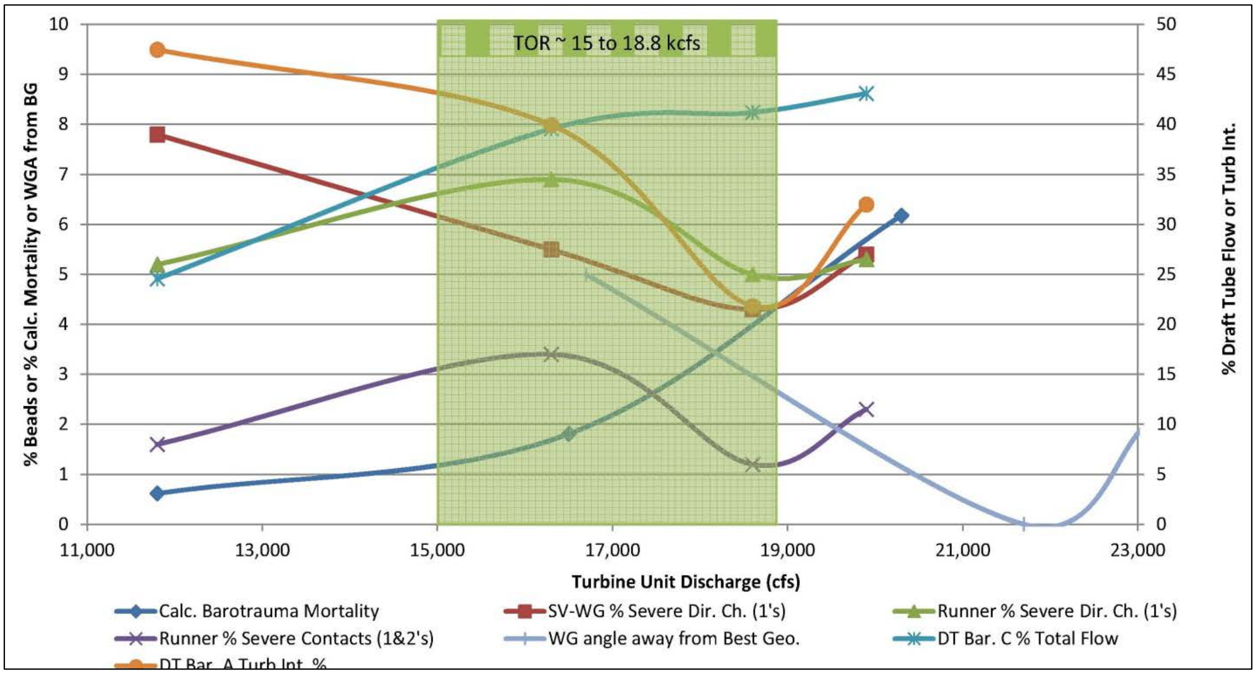


2.5. DISCUSSION

The preceding sections presented the available turbine survival information applicable to John Day turbines. This information comes from geometry considerations, physical model data, laboratory studies, field passage and survival studies, some CFD analysis, and sensor fish studies. None of the information alone can identify a target operating range for survival of fish passing through turbines. While the biological studies performed in the field may attempt to measure the direct mortality of fish passing through the turbines, all studies to date have limitations and may not accurately estimate mortality for run-of- river fish passing through turbines with natural depth acclimation and without tag burden.

The turbine physical model provided valuable information on physical injury inside turbines, especially with the bead passage analysis. However, the model data did not indicate the frequency of barotrauma injury and did not account for fish behavior. The barotrauma injury rate can be inferred from using the sensor fish combined with the CFD data (Carlson et al. 2010; Kiel and Ebner 2011) and the laboratory data (Carlson et al. 2010). These various sources of information have been combined in Figure 21. This figure only shows information that point at direct turbine mortality factors. It is important to remember that all the information is not equal since calculated pressure mortality would likely be mortalities, while direction changes and draft tube turbulence would only factor into injury and possible mortality.

Figure 21. Combined Information on Direct Turbine Mortality



Based on information provided in the various studies and summaries in this appendix, the recommended TOR is 15.0 kcfs to 18.0 kcfs at approximately 100 feet of head (see shaded area on Figure 21). At different heads, this flow range would change slightly. This TOR is consistent with the most open geometry and with bead strike data and draft tube conditions from the physical model. However, due to the concerns with barotraumas and low nadir pressures, the upper part of the range is limited to approximately 18.0 kcfs. The lower part of the range at 15.0 kcfs was selected to avoid the poor hydraulic conditions that appear near the lower 1% operating point, while allowing a large enough operating range to permit operating flexibility.

3. DEFINE TARGET PROJECT OPERATIONS

The John Day tailrace has a number of areas that influence tailrace egress from the project. Downstream of both the powerhouse and spillway, river thalwegs (e.g., channels), are separated by shallows in the near dam tailrace area and islands further downstream. These areas compose bathymetric obstacles to smooth tailrace egress. In addition, the contraction of the south shore in and around the area near the JBS outfall acts to force flow from turbine units 1 to 4 on a northern trajectory. These areas, in concert with spillway and powerhouse operations, act to form a variety of flow patterns and eddies that are not conducive to rapid downstream fish egress. Such flow patterns and eddies move either clockwise or counter-clockwise depending on project operations. As a result, tailrace flow patterns vary considerably, depending upon tailrace water elevations and flow levels from the spillway and powerhouse. For this reason, attaining reasonable tailrace egress conditions depends on maintaining balanced flow levels between the powerhouse and spillway. In addition, the presence of the four skeleton bays provides a gap in water flow where predator species can reside. This gap creates either a localized eddy just downstream of the skeleton bays or a significant stagnant region in the same area, depending on project operations.

With these difficulties in mind, in March 2012 the powerhouse egress at John Day Dam was evaluated in the 1:80 general model at ERDC. The modeling focused on low flow conditions were egress is more challenging. The river discharges investigated were 250 kcfs, 200 kcfs, 150 kcfs and 100 kcfs. Turbine unit discharges of 15.30 kcfs were used as a starting point representing current operations but were adjusted up and down for several model runs. Spill was modeled at 40%, 30%, 20% and 0% with and without TSWs with the existing fish passage plan patterns.

The modeling concluded that the unit priorities identified in the FPP were reasonable. Block loading the powerhouse (north and south ends) does not improve powerhouse egress due to the large area between bulked flows (either powerhouse bulked flow or spillway bulked flow) causing recirculation cells moving flow upstream. Therefore the existing pattern with TSW's installed is still recommended (5, 1, 3, 16, 14, 12, 10, 8, 15, 2, 11, 7, 4, 13, 9, then unit 6). When the spillway is in operation, powerhouse egress is reasonable when seven units are operational (at any unit operating point). Direct survival may increase if operating higher in the 1% operating range, but egress would diminish somewhat if that operation resulted in operating less than seven units. In general, powerhouse egress improves with reduced spill but especially at low river flow (below 150 kcfs). In fact below 150 kcfs, the TSW had very poor egress and project egress was better with 0% spill rather than 20% spill. However due to the significantly higher survival from spill per existing passage and survival studies, spill reduction is not likely.

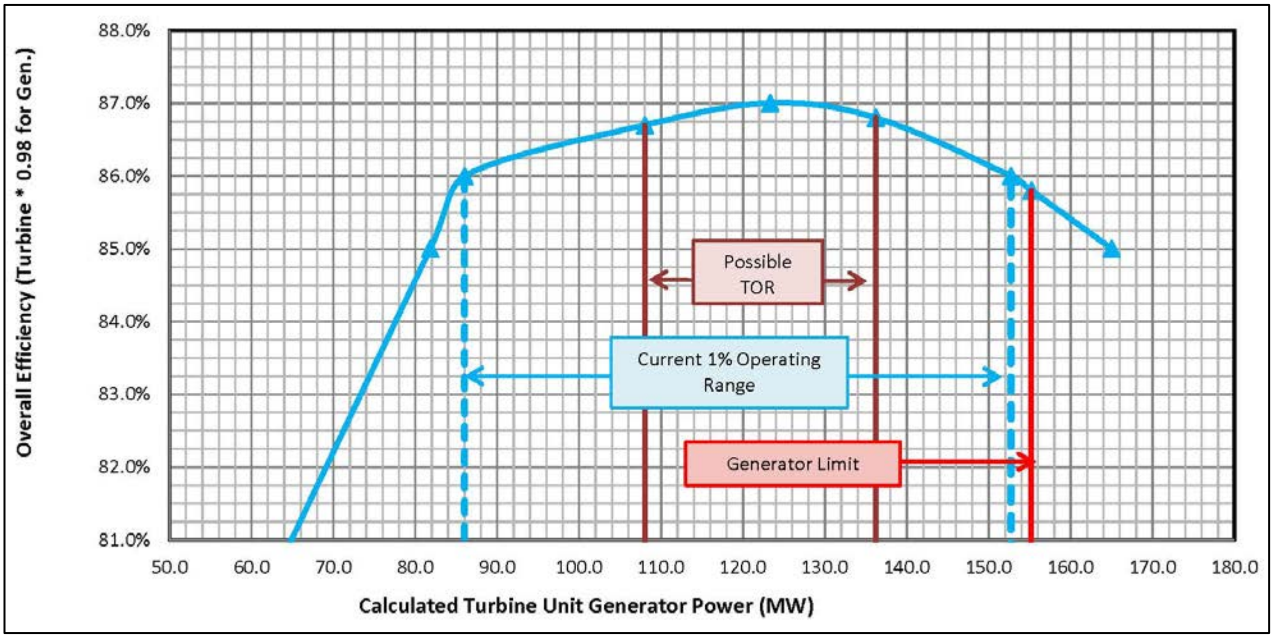
4. OTHER CONSIDERATIONS

Since the proposed TOR is within the current operating range for John Day, there should be little to no effect on the JBS. No other considerations have been identified for John Day at this time.

5. RECOMMENDED PATH FORWARD

The information presented in this appendix indicates that turbine unit operation may have a significant effect on direct turbine mortality at John Day. Based on information provided, the recommended TOR is 15.0 kcfs to 18.80 kcfs at approximately 100 feet of head. At 100 ft of head this TOR range approximately equates to 108 MW to 136 MW which is within the existing 1% range. This TOR is consistent with the most open geometry and with bead strike data and draft tube conditions from the physical model, while accounting for the concerns with barotraumas and low nadir pressures at the higher operating discharges.

Figure 22. Proposed Target Operating Range at 100 ft of Head for John Day Turbines



The exploration of target project operations resulted in no change to the current unit priority. With spill at the current levels, turbine egress looks adequate when at least seven units can be operated. Below this number of units operating, significant recirculation can occur.

The TSP team proposes that a thorough turbine survival test be conducted at John Day to establish whether increased survival is seen under the TOR conditions. Indirect mortality (i.e., predation) is considered to be a large portion of total turbine mortality; therefore, any TST must make the project operating conditions as similar as possible while testing the different unit operating conditions.

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