# Appendix A: Prototype Investigations

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# Appendix A: Prototype Investigations

## A.1 Biological Test Preparations

### A.1.1 McNary 1999 Biological Test

Determining the one-percent efficiency operating conditions for the biological field-testing proved difficult due to the issues surrounding the selection of turbine operating points for the testing. Although using historical methods to determine blade to gate relationships (cam curves) was an option, the assignment of the performance based on efficiency was unclear and contained substantial uncertainty. Field-tests were performed on McNary Unit 5 in 1998 to confirm turbine performance modeling assumptions (model testing 1993 to 1997) and to investigate the applicability of revised evaluation techniques for use on McNary. Other index tests were performed using Winter-Kennedy methods. (Winter 1933). The results of this comparative field-test were published in a field test report entitled *Turbine Performance With and Without Fish Screens McNary Powerhouse. Unit 5*. The test included using ASFM (scintillation technique of flow measurement) and Winter-Kennedy flow measurements (historical method) for conditions without screens and with ESBS screens installed using on cam information derived from model testing and the 1993 field-testing (historical). The without screens condition comparing results of each technique is shown in Figure A - 1. It is clear from the graph that a deviation exists using historical Winter-Kennedy methods at the higher outputs when compared to other measurements (the Winter-Kennedy method is indicated by blue and black dashed lines). The goal of these investigations was to better identify turbine performance as it relates to one-percent operating limits. Figure A - 2 shows the results with ESBS screens installed. Again, the historical Winter-Kennedy (red dashed) methods over-predict turbine performance at higher power levels.

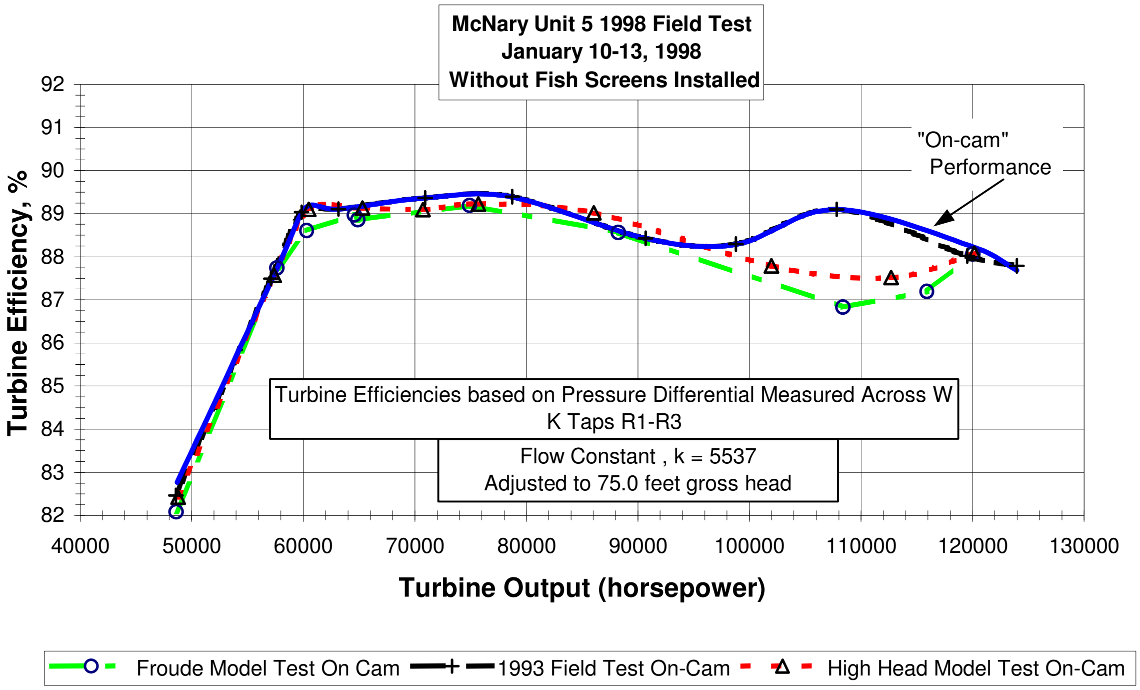
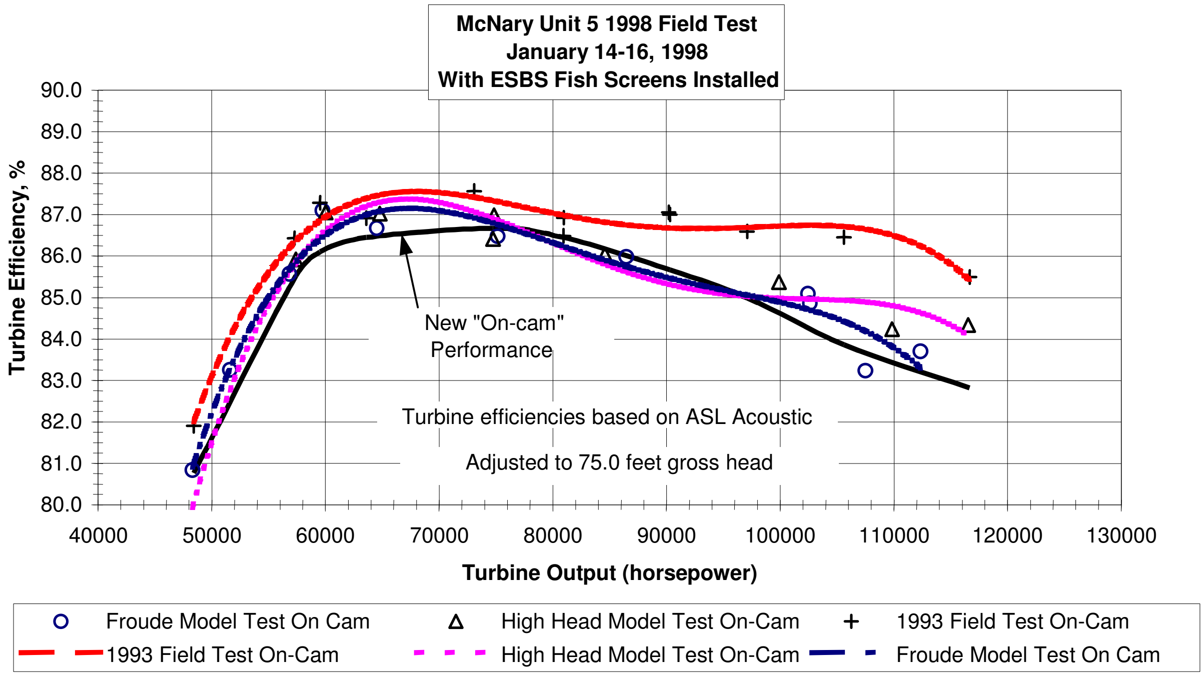


Figure A - 1. Results of 1998 field index test using the Froude and Reynolds model cams without screens.



Generator Output MW = (Turbine Horsepower)(0.0007457)/(.98)

Figure A - 2. Results of 1998 field index test using the Froude and Reynolds model cams with ESBS

A testing summary comparing predicted to measured values for the three conditions tested, at 75 feet of head, resulted in the following conclusions:

- The installation of ESBS screens causes approximately a 2.5 percent loss in turbine efficiency and a 6 percent loss in full load capacity.
- Significant differences exist between the predicted turbine performance and what was actually measured. The primary uncertainty resides in the development of the curve shape, which can over or underestimate the actual one-percent operating limit.
- The revised technique of turbine performance prediction resulted in a reduction in the uncertainty of using Winter-Kennedy relative flow information for performance prediction and in establishing one-percent operating limits from existing data.
- The scintillation technique of flow measurement appears to provide a reasonable estimate of relative flow.
- The revised blade-gate relationship resulting from this test should improve turbine efficiency from zero to one percent above the previous best information over the range of operation.
- The proof of concept design for the modernized NPR 3-D controller worked well controlling the unit to achieve the desired blade-gate relationships.

After the conclusion of the field test, final on cam blade-gate relationship tables were developed, installed, and tested using both the existing 3-D cam controllers and the modernized NPR 3-D cam controllers. The tuning of the Unit 5 turbine in preparation for the biological testing was completed. The modernized 3-D controller was placed in independent operation and functioned admirably until the Unit 5 generator failure, thus biological testing was shifted to Unit 9. Unit 9 was calibrated, the NPR 3-D cam was installed, and on cam information and settings were applied to Unit 9 at McNary with a check index test to occur in July 1999 after the biological testing was completed in June 1999. Results of that testing indicated that the performance for Unit 9 was almost identical to that of Unit 5 and that the selected biological test point of 12,400 cfs (upper end of one percent) is accurate. Figure A - 3 shows the comparison of the results of the testing and the biological test point.

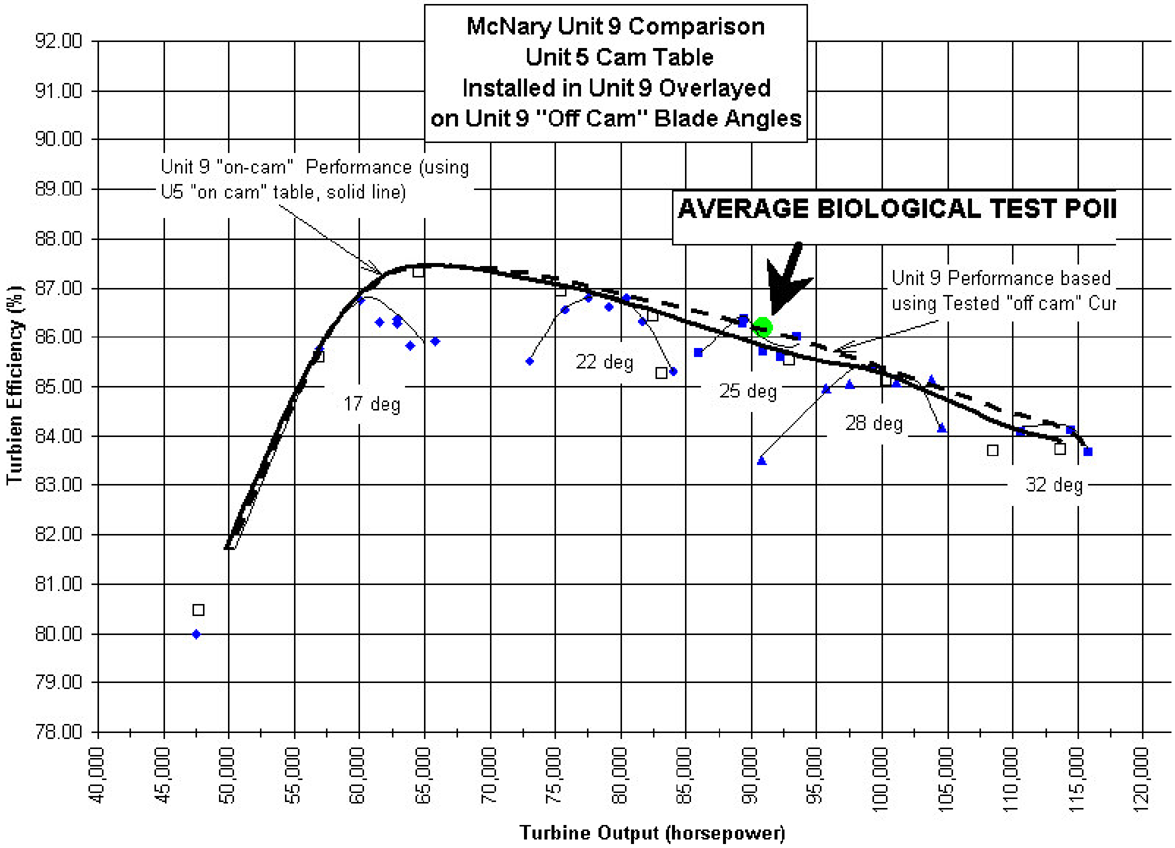


**Figure A - 3. McNary turbine performance and actual average biological test point**

## A.1.2 Bonneville I Units 5 & 6 Biological Test

### A.1.2.1 Unit 5

During FY98-99, engineering preparations for the biological testing of Units 5 and 6 were undertaken. A delay in the biological testing occurred because of installation problems with the rehabilitated machine (Unit 6). In addition, there were scheduling conflicts with other ongoing programs currently underway at the Bonneville project. Significant effort was necessary to coordinate and execute the necessary work within limited time frames. As part of the PSC studies (Surface Collector), a field test of an existing turbine was desired to better define the effects of the surface collector on turbine performance. The installation of the PSC in the intake of the existing units had adversely affected turbine operational performance. In order to reduce costs and eliminate duplicate efforts, a single field index test series was coordinated to accomplish an evaluation of the surface collector effects on turbine performance and to tune existing Unit 5 for the biological test. Various brochures, instructions, and guides were published prior to the testing. Unit 5 was mechanically calibrated prior to testing.

Unit 5 was tested under three operating conditions: (1) with PSC and STS screens installed, (2) with STS screens installed, (3) with no devices installed. The biological test was conducted with STS screens installed. The ASFM system and the necessary frames were procured and used during the testing. The results of this test are published in *Bonneville First Powerhouse. Cascade Locks. Oregon. Unit Performance Test Unit 5.* Volumes I, II, and III. Figure A - 4 shows the resulting performance from tuning Unit 5 for the biological testing. This testing resulted in the following conclusions:

- The installation of PSC and STS screens causes an approximate loss of 5.0 to 7.0 percent in unit efficiency.
- The installation of STS screens causes a 1.8 to 2.5 percent loss in unit efficiency.
- Measured performance differences between the conditions resulted in significantly different one-percent operational limitations.
- The revised technique of turbine performance prediction resulted in a reasonable correlation over the normal operating range of the unit.
- The scintillation technique of flow measurement appears to provide a reasonable estimate of relative flow.
- The revised blade-gate relationship resulting from this test should improve turbine efficiency from zero to one percent above the previous best information.

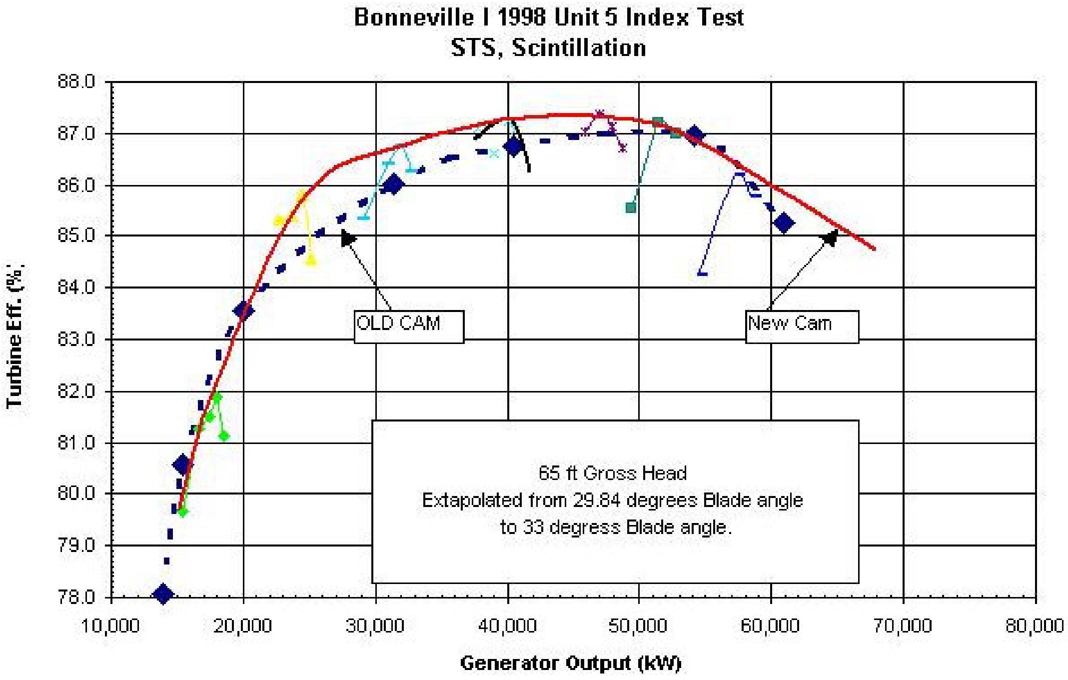


**Figure A - 4. Bonneville I Unit 5 cam used for the biological test**

After the conclusion of the field test, final on cam blade-gate relationship tables were developed, installed, and tested for function. Revised one-percent operating limit tables were prepared and coordinated with the Region for the existing units. The tuning of Unit 5 turbine, in preparation for the biological testing, was completed.

### A.1.2.2 Unit 6

After installation of the new Minimum Gap Runner in Unit 6 was completed and the necessary commissioning and operational testing was performed, the new design was index tested to establish the operational cam curves and operating limits for the new turbine design. The testing was performed both with and without fish screens installed. Other testing was performed with different surface collector configurations and is not reported herein.

Figure A - 5 shows the resulting performance from tuning Unit 6 for the biological testing. This testing resulted in the following conclusions:

- The installation of STS Screens causes a 0.6 to 1.0 percent loss in unit efficiency.
- Measured performance differences between the conditions resulted in different one-percent operational limitations.
- The revised technique of turbine performance prediction resulted in a reasonable correlation over the normal operating range of the unit.
- The scintillation technique of flow measurement appears to provide a reasonable estimate of relative flow.
- The turbine met contractual requirements.

After the conclusion of the field test, final on cam blade-gate relationship tables were developed, installed, and tested for function. One-percent operating limit tables were prepared and coordinated with the Region for these new units. The tuning of the Unit 6 turbine, in preparation for the biological testing, was completed.

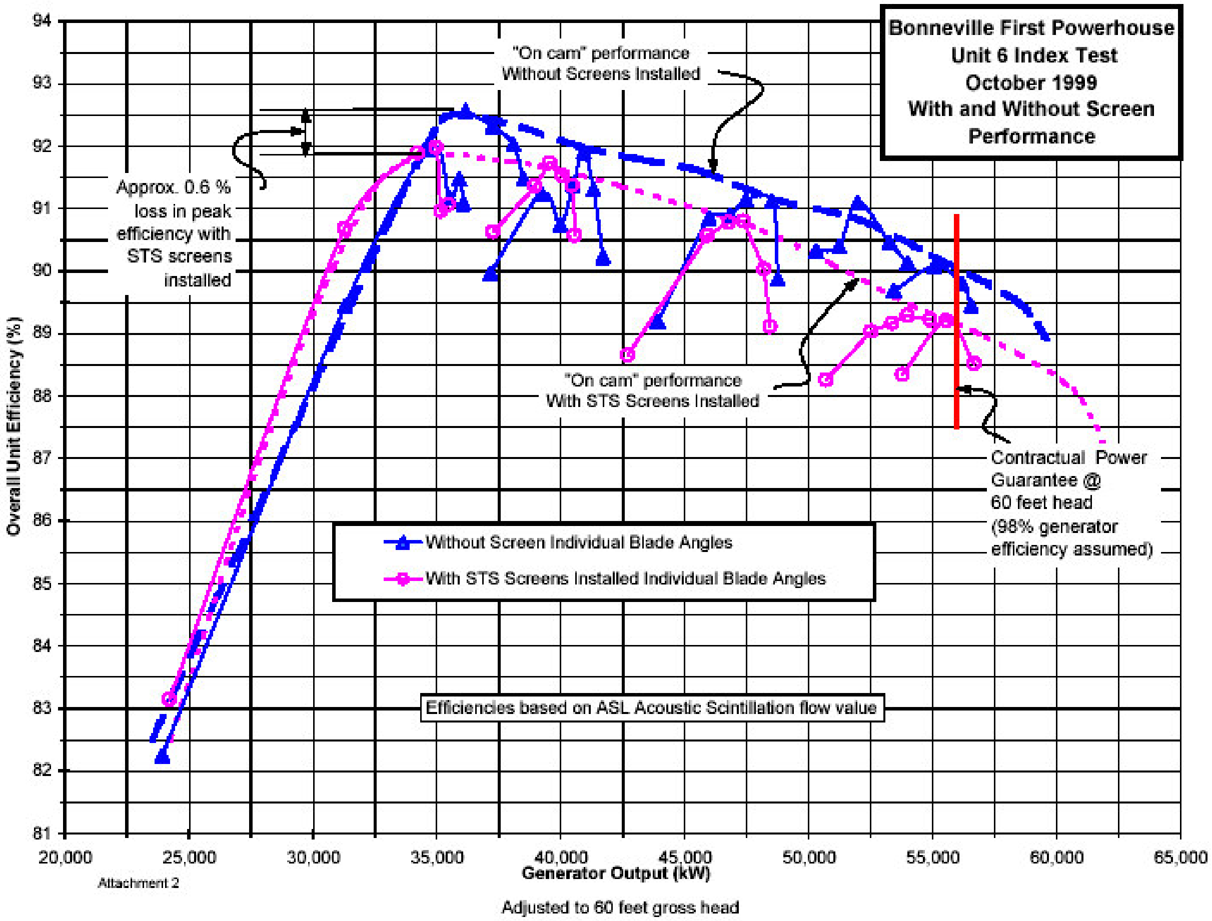


**Figure A - 5. Bonneville I Unit 6 used for the biological test**

### A.1.2.3 Unit 5 and Unit 6 Biological Test

The one-percent operating limits of each machine were tested during the biological testing. Staff was on site to daily prepare each turbine prior to the beginning of biological testing and remained on site to ensure turbine operation conformed to the biological test plan. The desired positioning and the average condition for each machine during the 60 days of biological testing is shown in Figure A - 6. The figure compares desired to actual operational results.

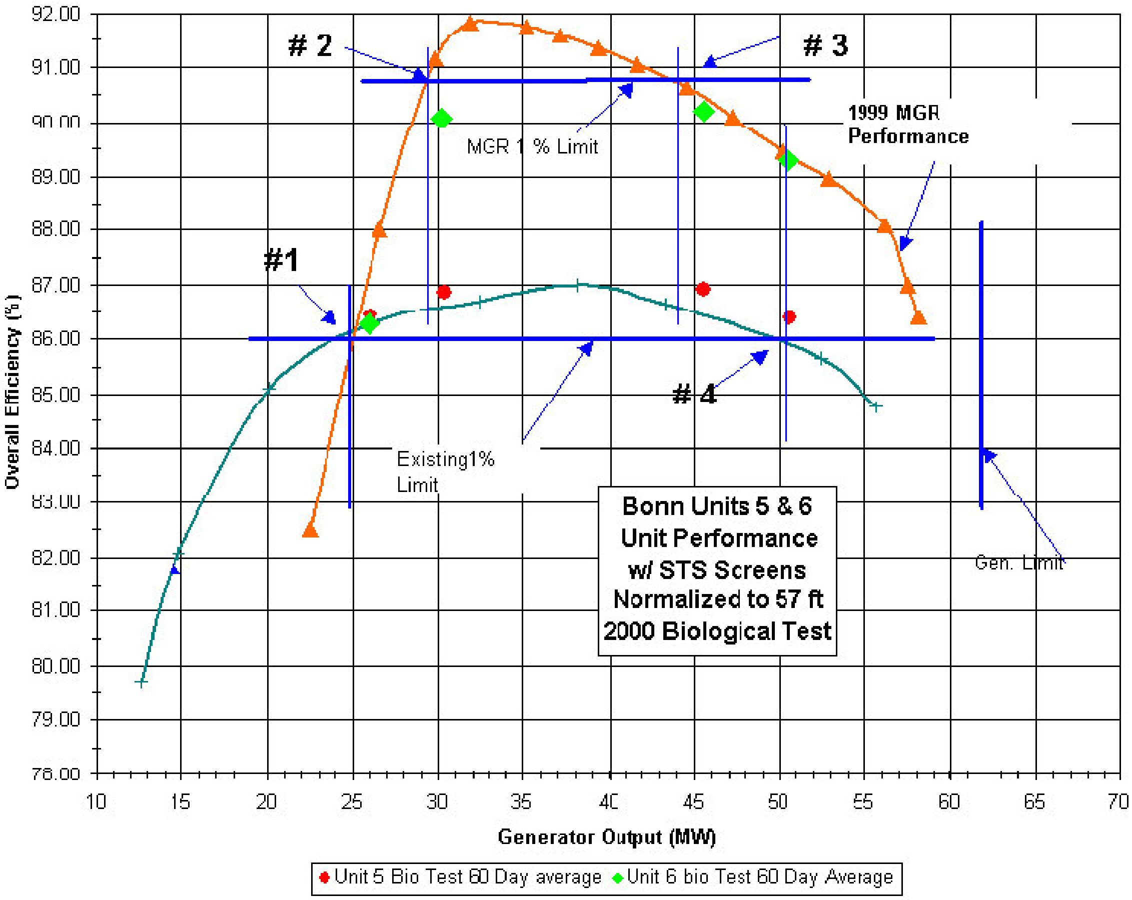


**Figure A - 6. Bonneville Units 5 and 6 biological test points**

### A.1.3 Lower Granite Unit 4 1994 and 1995 Biological Test

The 1994 biological tests were performed at the upper one-percent power limit on a turbine without any adjustments for operational improvements (untuned turbine). In 1995, field-tests were performed on Lower Granite Unit 4 to establish a record of the unit performance with and without fish screens and ultimately to develop new cam curves. The results of this comparative field-test were published in a three-volume field-test report: (1) without fish screens (No Screens, NS) installed, (2) with STS installed, and (3) with ESBS installed. The test included using Winter-Kennedy flow measurements and pilot studies for time of travel and scintillation flow measurement techniques for without screens, STS, and with ESBS screens installed using on cam information derived from the 1975 model test. This testing resulted in the following conclusions:

- The installation of ESBS causes approximately a 6.7 percent loss in full load capacity.
- The scintillation technique of flow measurement appears to provide a reasonable estimate of relative flow for both with and without screens.
- The time of travel flow measurement technique performed well without screens installed, but did not perform reliably with screens installed.

- The revised blade-gate relationship resulting from this test should improve turbine efficiency 2 percent above the previous best information.

After the conclusion of the field test, final on cam blade-gate relationship tables were developed, installed, and tested for the existing 3-D cam controllers. There was no staff on site during the 1994 biological testing. Turbine data for the biological testing period was obtained from the project. In 1995, staff was on site to daily prepare the turbine prior to the beginning of biological testing and remained on site to ensure operation of the turbines conformed to the biological test plan. The average operating condition during the biological testing is shown in Figure A - 7.

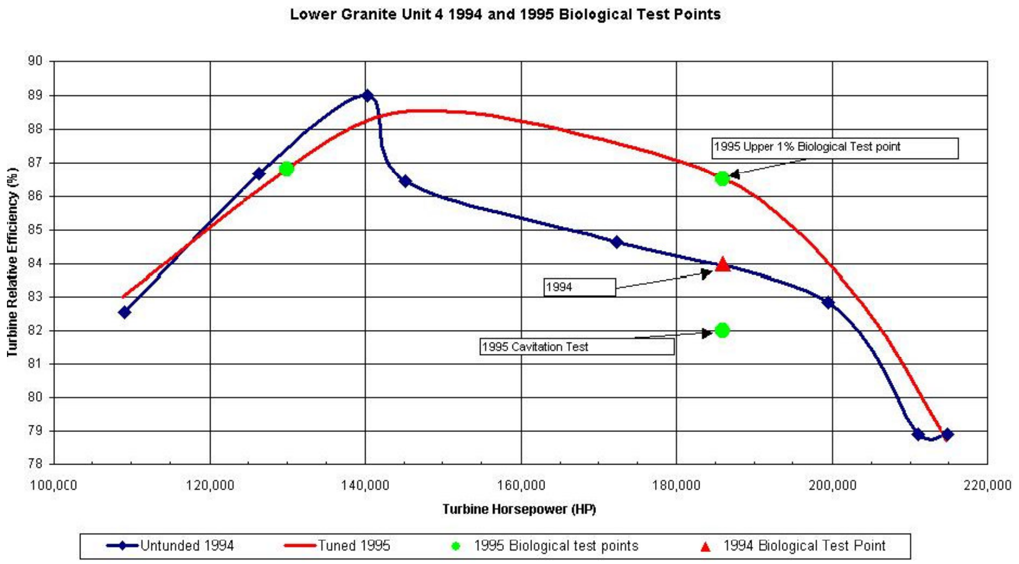


**Figure A - 7. Lower Granite 1994 and 1995 biological test points**

## A.1.4 Fish Release Pipes

In order to test the hypotheses that turbine runner blade clearance gaps were potential sources of the fish injury and mortality, a means of placing fish near these locations in the turbine was required. A location for potential release of fish to pass these areas was determined at WES-ERDC using hydraulic models. An engineering concept design was developed and implemented. The piping was biologically tested prior to implementation and approved for use by the Region. The system design was completed and installed at McNary as a pilot test case and at Bonneville I for the biological tests of Units 5 and 6. The concept design and the implementation proved to be an engineering success meeting all technical requirements. The following five figures (Figures A - 8 to A - 12) show the concept and arrangement of the fish release piping systems.

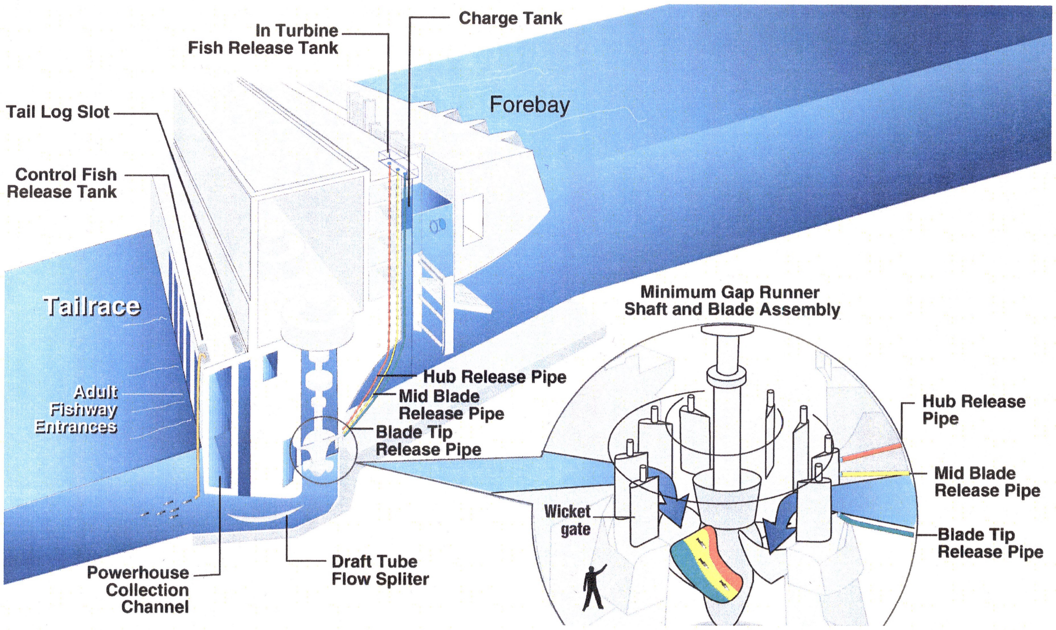


Figure A - 8. Concept of release pipes for Bonneville I Unit 6

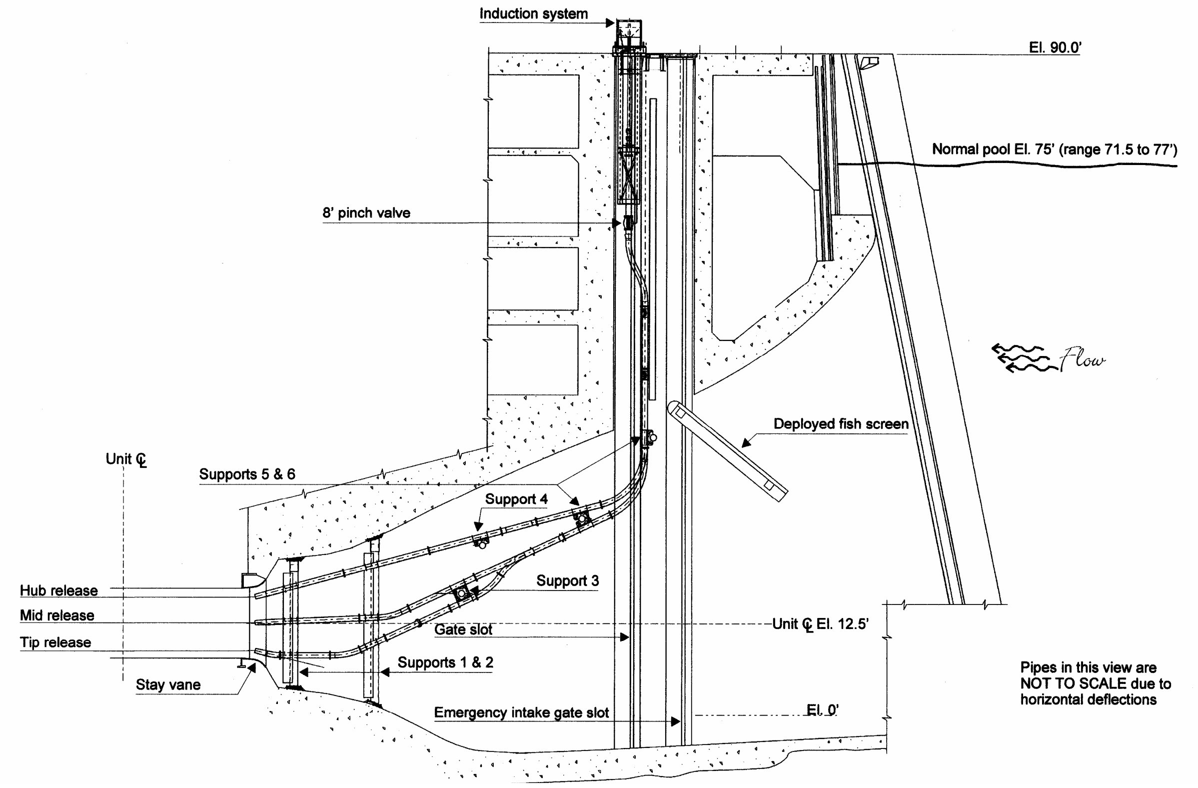


Figure A - 9. Cross-section of release piping for Bonneville Unit 5

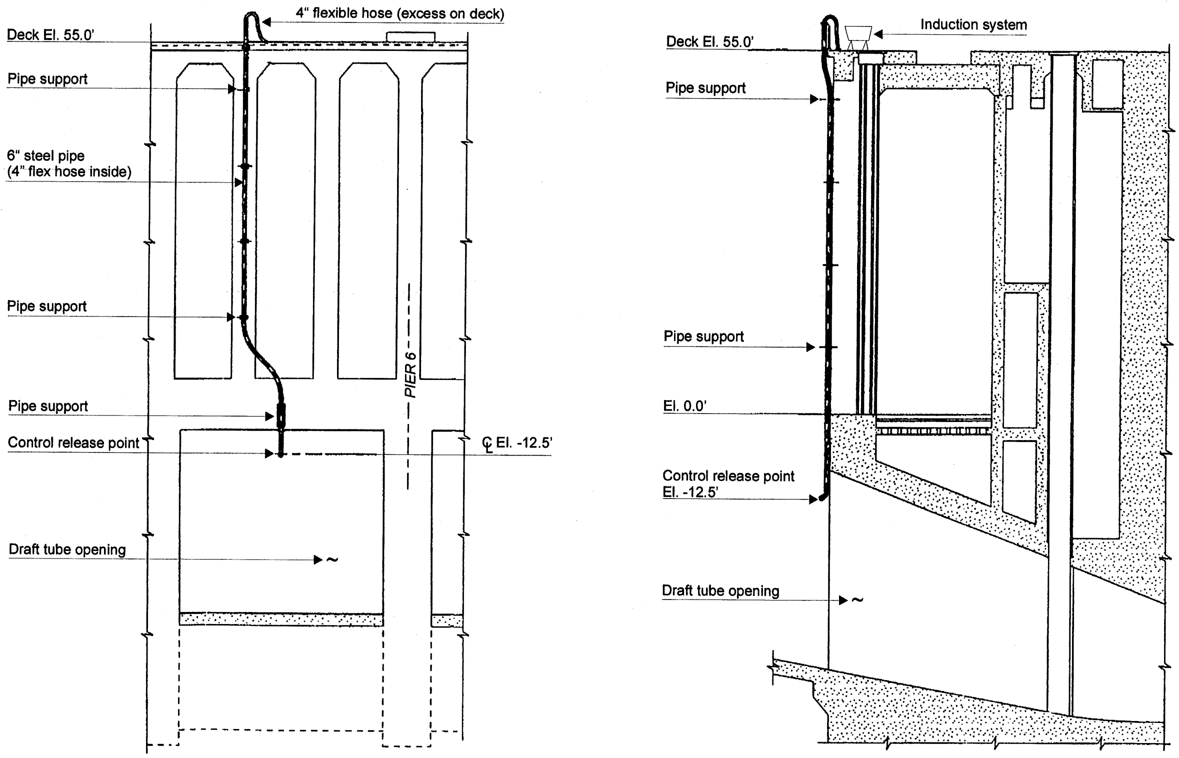


**Figure A - 10. Typical draft-tube release pipe for Bonneville I testing**

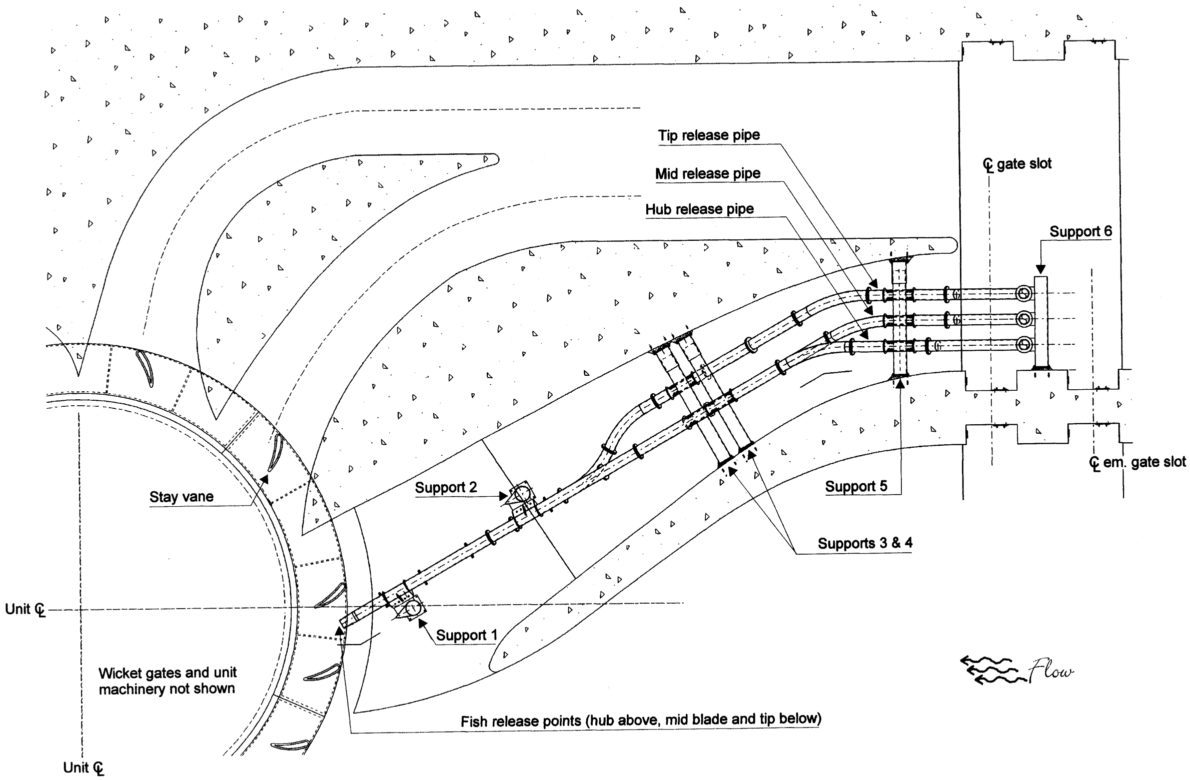


Figure A - 11. Plan view of the release pipe system for Bonneville I

Upper and middle release pipes, and video cameras

Lower and middle release pipes

Another view of release pipes

Figure A - 12. Photos of McNary fish release piping at stay vane

## A.2 Index Testing

Index tests are run on Kaplan turbines to establish the optimum blade-gate relationship. This is often referred to as tuning, much like adjusting an automobile for optimum gas mileage. The testing is performed to essentially meet field-testing code requirements for measurement accuracy and to establish a minimum accuracy level for acceptable data reduction. The tests are performed after a careful calibration of the mechanical components and test instrumentation. The measurements include forebay and tailwater measurements at the selected unit, power measurements from the current and potential transformers, blade and gate position and relative flow measurement. From this information, a relative efficiency can be computed for each test point. A typical test measures approximately 125 test points and takes about three days to complete. The analysis of the data and preparation of the final on cam data tables and operational tables requires up to 120 days to develop and coordinate prior to implementation of new data. Figure A - 13 shows the process, which is explained below.

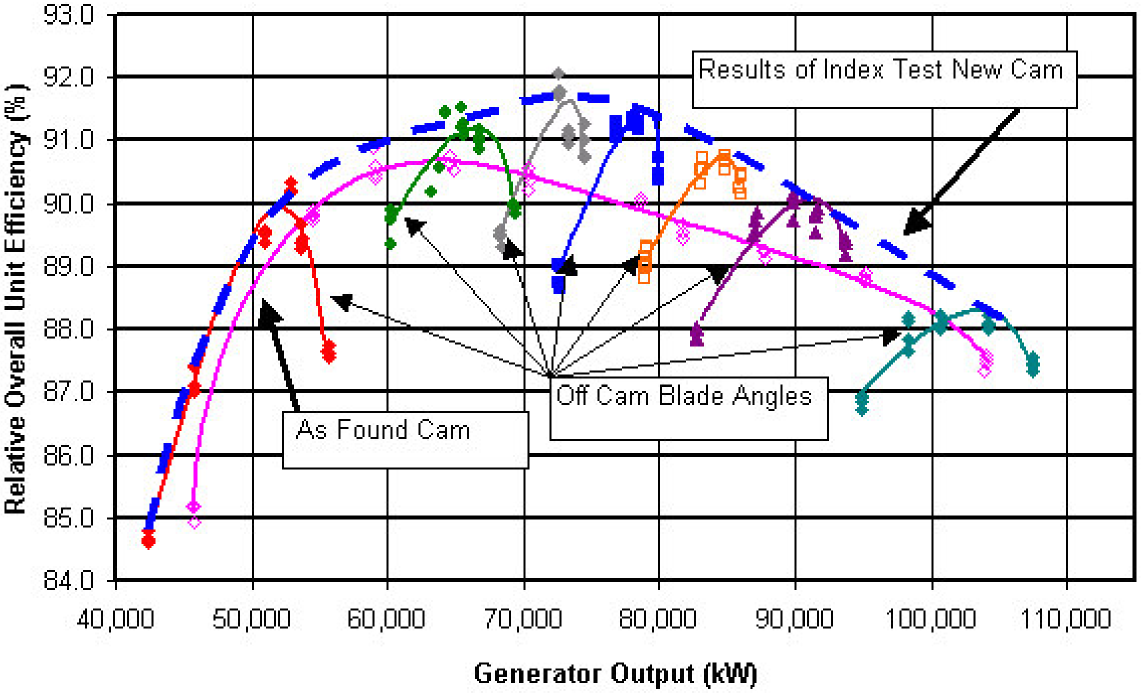


Figure A - 13. Example of index test process and improvements

- As Found Cam - An initial test is run using the existing on cam information stored in the governor control system. The testing occurs at specific wicket gate positions to which the blade angles are adjusted for optimum performance. A curve is then drawn to establish a baseline performance, to which individual fixed blade angles performance can be compared, to establish if the existing cam information is optimum for the machine being tested.

- Off Cam Blade Angles – In order to determine the wicket gate opening at which a particular blade angle achieves its optimum performance, a series of test points are required for each blade angle tested. Normally five to seven blade angles are selected that generally coincide with the original model performance test, which established the original design settings and conditions. At each of the blade angles, five to ten wicket gate positions are measured. At each of the wicket gate settings, two to five test runs are made to collect data to establish an average value. The various data points can be seen on the graph. After the off cam data has been collected, curves are constructed through the family of data for a particular blade angle. It is clearly apparent from this typical test data that the existing on cam data needs to be corrected to achieve optimum turbine performance. A computer algorithm is then used to reduce the data into finer detail. This algorithm plots individual data points (several hundred) based on smooth curves drawn through other graphs of power versus wicket gate position, and relative flow versus wicket gate position, resulting in an accurate representation of the collected test data. This code accepted method provides an off cam curve representative of the data without being influenced by particular data measurement points. The data is then ready for initial on cam data reduction for the common test head occurring during the index test.
- New Cam – The results of the index test off cam testing are converted to on cam operational tables. This process begins with establishment of the field-tested new cam information. This information is then combined with other existing information and model test information to produce a cam curve. A cam curve is the loci of blade and gate positions that produce optimum performance for a particular head on the turbine. That optimum curve is shown as the dashed line on Figure A - 13. As the data from the index testing is incorporated into existing information, care must be taken in the shape of the curve and physical mechanical properties of the turbine. For any blade angle, any number of wicket gate positions may produce reasonable performance, but only one will result in the optimum. Since only a few blade angles and wicket gate positions are actually tested, there are compromises in establishing a smooth cam curve in order to produce smooth transitions in mechanical operation. Therefore, experts experienced in Kaplan turbine operating characteristics and the limitations of the turbine machinery develop these cam curves. An example of the before and after results of a previous index test are shown in Figure A - 14. Note the difference in geometry resulting from tuning the turbine through index testing.

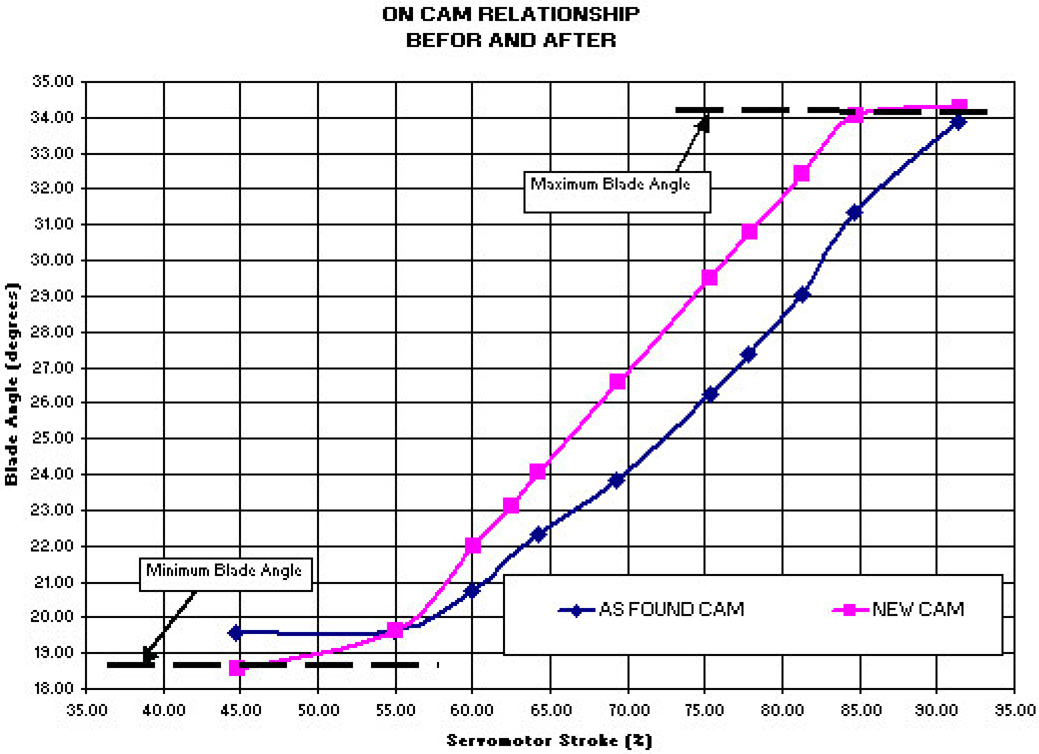


**Figure A - 14. Example of change in turbine geometry before and after index testing**

- The On Cam Curve Family – The results of the index test at one operation head is used to define the entire turbine operating range combined with the model test information, which has investigated the full range of operation. A family of cam curves is then developed for the operating head range and power output. This family of curves is transformed into data tables understandable by a governor computer control program and installed in the governor. Figure A - 15 illustrates a complete family of cam curves for the operating range of a Kaplan turbine.

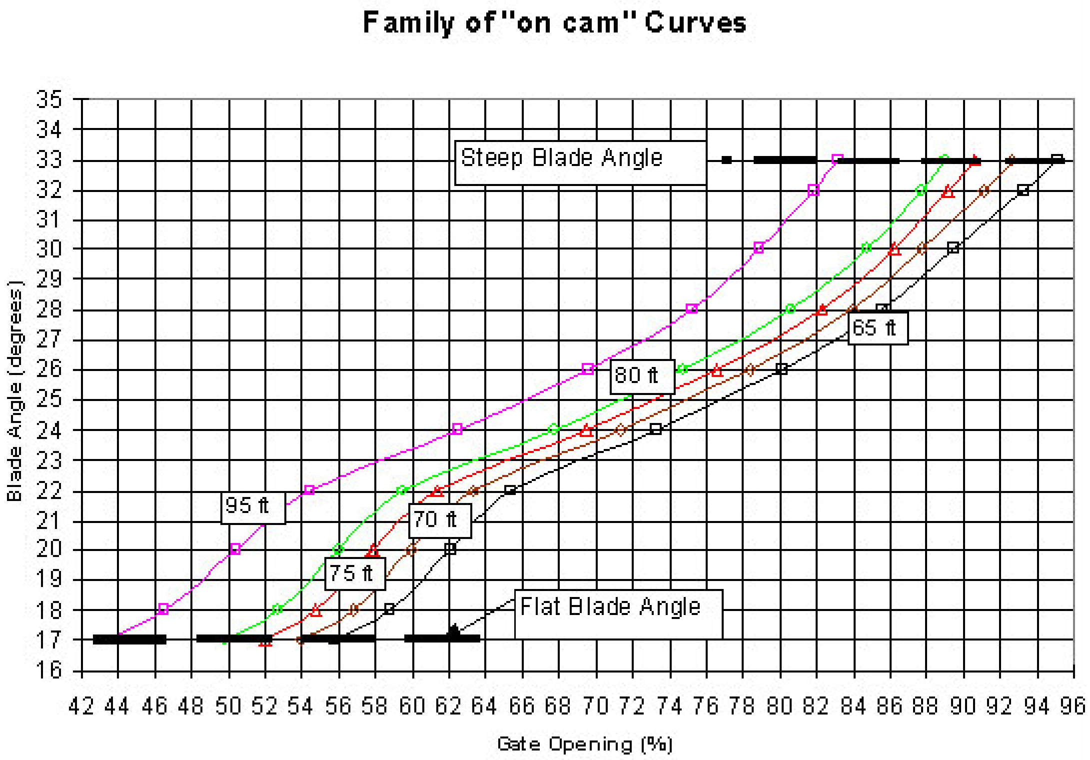


**Figure A - 15. Family of on cam curves for a Kaplan turbine**

- <u>Unit Performance Curves</u> – The raw information and data obtained from field-testing is now reduced to a single operating head condition over the operating range of the turbine experienced during a field test. As the turbine passes more water, the hydraulic conditions across the turbine fluctuate in real time and continually experience perturbations. In order to normalize the data collected, time averaged data and standard equations, based upon geometric and hydraulic similarity, are used to normalize the information for developing normalized turbine performance information for an entire index test. Outliers, or data exceeding test code variation limitations, are eliminated in the data reduction but are presented in the report for information. This process uses hydraulic *affinity laws*. These laws allow flexibility in reducing data for evaluation given the changing conditions within a field test or model test. Three basic equations are used and they are generally related through head. These are the efficiency equation of turbomachinery, flow affinity equation, and the power affinity equation.
- <u>With and Without Screens Cams</u> – Index testing has revealed that the on cam relationship of the gates and blades changes with the installation of fish diversion devices in the intake. This has required that index tests be performed both with and without fish diversion devices in place. Turbine performance is also different, requiring the development of turbine performance for each condition. Examples of the differences in on cam curves and turbine performance are shown in Figure A - 16 and Figure A - 17.

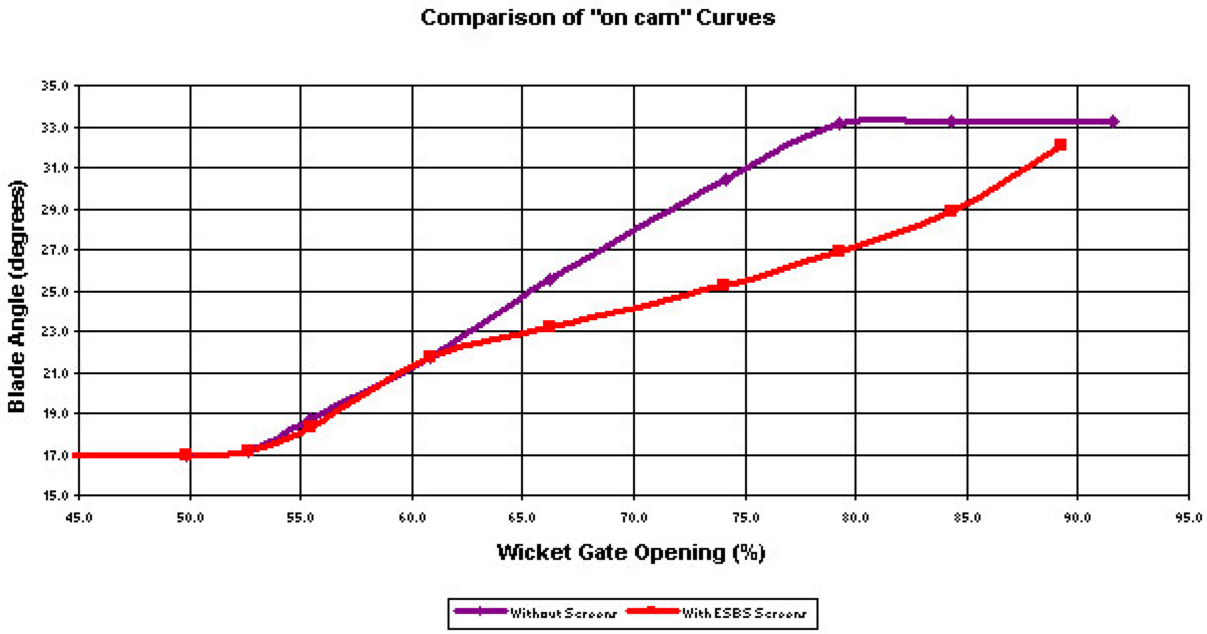


Figure A - 16.  Comparison of on cam curves with and without screens

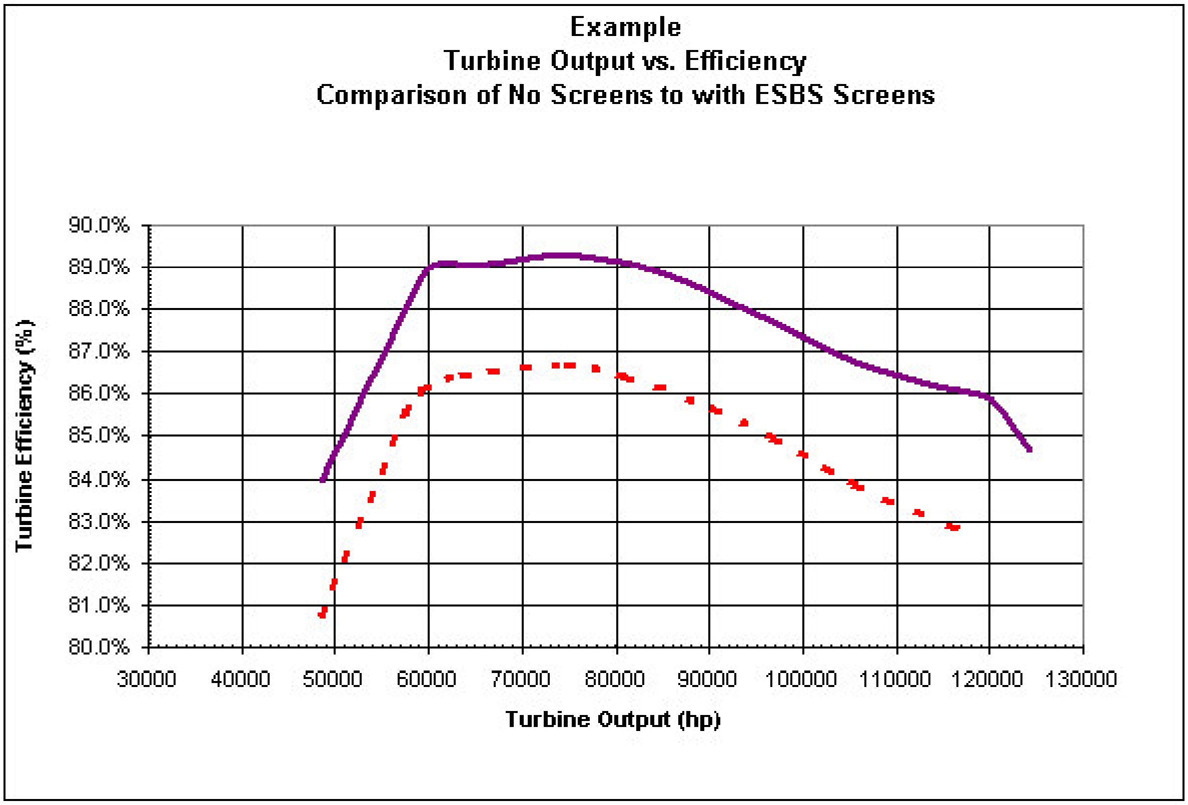


Figure A - 17. Example turbine vs. efficiency with and without fish screens

The preceding information is checked, collated and interrogated to develop the information needed for the various turbine operational tables. This information is then coordinated with the regional and project authorities such as the Fish Passage Plan and FPOM and installed in the system turbine operating control systems.

During FY98-99, it became clear that to operationally optimize the McNary turbines, the existing Seawell 3-D cam controller was inadequate and obsolete. This device was the first electronic 3-D cam installed on a Corps turbine in this region and had limitations and features that caused difficult operational maintenance and unattended use. An effort was undertaken to correct the deficiencies for the Unit 5 controller to adequately control the unit for subsequent engineering and biological testing. The replacement of the Seawell 3-D cam electronic control unit (ECU) caused a review of the existing North Pacific Division (NPD) 3-D cam operation on other COE projects in the region. The COE Operations and Maintenance (O&M) Division evaluated the actual operation of the existing NPD 3-D ECU. The results of the evaluation indicated that the ECU was obsolete and unsuitable for satisfactory incorporation into the system wide control (GDACS) upgrade being implemented.

A coordinated engineering effort between the TSP team and the GDACS team resulted in an O&M funded program to investigate, design, procure, test and replace existing NPD 3-D controllers with a GDACS compatible design. This was designated the NPR 3-D cam that would, in the future, be capable of self-optimization of existing turbines. The TSP engineering team participated in the successful procurement, installation, and field-testing of the proof of concept design on McNary Unit 9. The NPR 3-D cam program is funded outside the CRFM program and is continuing to evolve a level of control suitable for precise operational optimization. The success of the improved operational controls has resulted in efforts (funded by other programs) to develop a system of controls and measurements to potentially allow individual unit optimization and precise electronic control. The implementation of such a program will require another eight years to implement and should be monitored by the TSP team and region to better establish and define turbine operational limits for fish passage improvement.

## A.3 Physical Measurements

### A.3.1 Runner Blade Angle

The determination of runner blade angle was historically left to the turbine manufacturers. Each manufacturer has a different method of establishing the operating location of the runner blades. This has created difficulty and confusion in the past when alterations in turbine performance occurred during maintenance operations. There is currently no internal turbine water passage method available to establish in service runner blade angles. It must be done externally through mechanical means (cables and linkages), which are subject to mis-adjustment and wear and tear. In order to standardize methods, a measurement technique was developed in 1993 to allow for standardization and consistent maintenance and operation adjustments. This method is explained below.

The runner blade angle is measured prior to field-testing in order to calibrate the oil head (supplies the oil pressure to move the blades), which in turns measures the actual blade angle through mechanical movement. This is accomplished with the turbine unwatered by locating two points on the discharge ring at the periphery of the blade in the flat over-travel position. One of these points is located near the trailing edge and one near the leading edge with both on the outer radius of the blade shape. Figure A - 18 shows how the blade position is drawn on paper while in the flat over-travel position. The vertical distance from the bottom of the discharge ring to these points is determined as well as the horizontal distance between these points. The oil head is then fitted with a temporary paper scale, which is calibrated to measure the blade angle. Figure A - 19 is a sample process of determining the blade angle for the temporary paper scale. Figure A - 20 shows the runner blade angle at the flat and steep positions.

**Figure A - 18. Example of tracing runner blade on discharge ring**

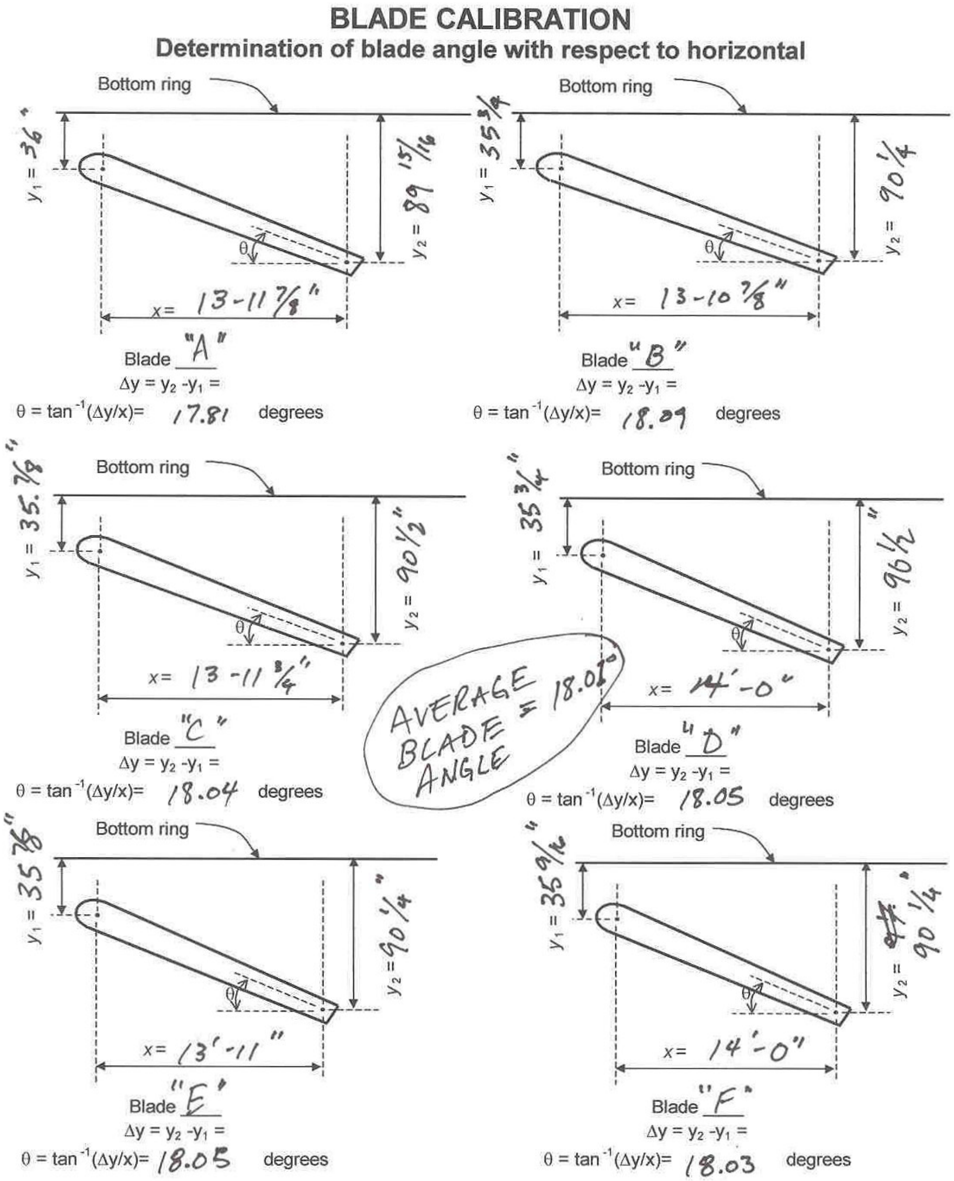


**Figure A - 19. Example of the computation of the individual blade angles**

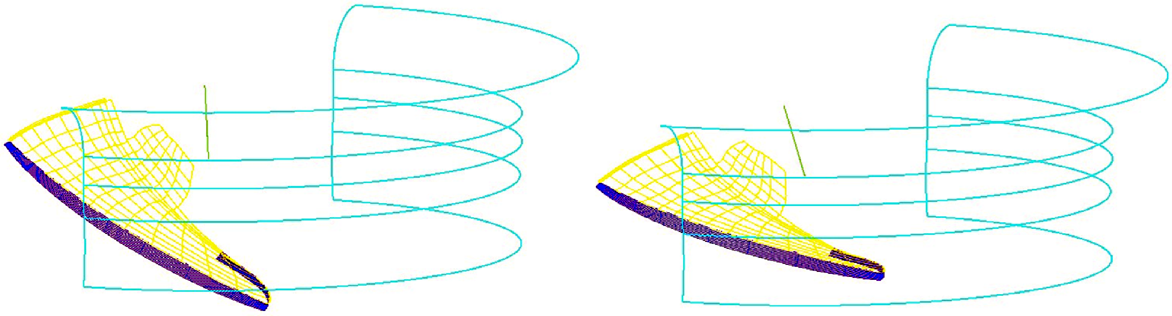


**Figure A - 20. Runner blade angles of 32 degrees (steep-left) and 17 degrees (flat-right)**

### A.3.2 Runner Blade Gaps

The blade gap is the distance between the blade and the discharge ring and the blade and the hub. Figure A - 21 is a drawing of a blade and tables A - 1 to A - 5 show where the measurements are taken.

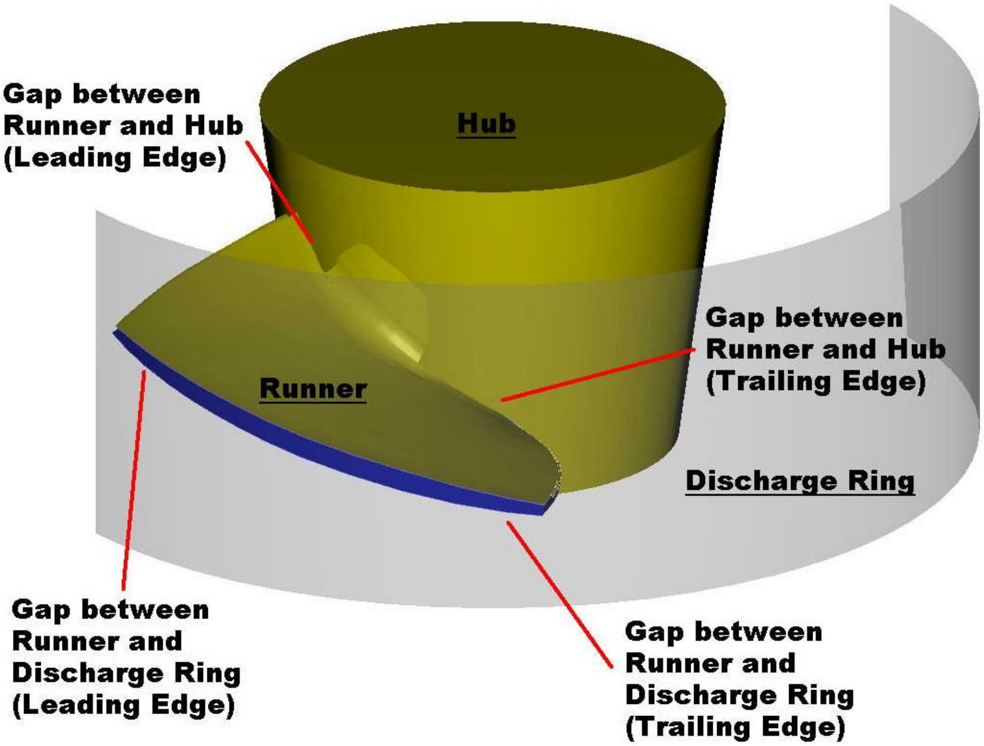


Figure A - 21. Example of measurement location of runner blade gaps

The following tables are examples of the gap measurements performed on the various turbines in the system. There is significant difference depending on the design of the blade and hub.

**Table A - 1. Bonneville Unit 5 existing runner blade gaps**

| | FLAT (As Measured) | MID (As Measured) | STEEP (As Measured) | CONDITION #1 | CONDITION #2 | CONDITION #3 | CONDITION #4 |
|---|---|---|---|---|---|---|---|
| | Blade Angle | Blade Angle | Blade Angle | Blade Angle | Blade Angle | Blade Angle | Blade Angle |
| | 5.502 | 18.932 | 33.702 | 13.4 | 16.1 | 25.6 | 28.9 |
| Distance from Leading Edge (inches) | TIP Gap (inches) | TIP Gap (inches) | TIP Gap (inches) | TIP Gap (inches) | TIP Gap (inches) | TIP Gap (inches) | TIP Gap (inches) |
| 0 | 0.75 | 2.375 | 10.25 | 1.71 | 2.03 | 5.93 | 7.69 |
| 6 | 0.6875 | 1.875 | 7.5 | 1.39 | 1.62 | 4.41 | 5.67 |
| 12 | 0.5 | 1.625 | 5.5 | 1.16 | 1.39 | 3.37 | 4.24 |
| 18 | 0.375 | 1.25 | 4 | 0.89 | 1.07 | 2.49 | 3.11 |
| 24 | 0.3125 | 1 | 2.75 | 0.72 | 0.86 | 1.79 | 2.18 |
| 30 | 0.3125 | 0.75 | 1.875 | 0.57 | 0.66 | 1.26 | 1.51 |
| 36 | 0.3125 | 0.625 | 1.4375 | 0.50 | 0.56 | 0.99 | 1.17 |
| 42 | 0.3125 | 0.625 | 1 | 0.50 | 0.56 | 0.79 | 0.88 |
| 48 | 0.3125 | 0.375 | 0.625 | 0.35 | 0.36 | 0.49 | 0.54 |
| 54 | 0.3125 | 0.375 | 0.5625 | 0.35 | 0.36 | 0.46 | 0.50 |
| 60 | 0.3125 | 0.375 | 0.5 | 0.35 | 0.36 | 0.43 | 0.46 |
| 102 | 0.375 | 0.375 | 0.5 | 0.38 | 0.38 | 0.43 | 0.46 |
| 108 | 0.5 | 0.375 | 0.625 | 0.43 | 0.40 | 0.49 | 0.54 |
| 114 | 0.5 | 0.4375 | 1.125 | 0.46 | 0.45 | 0.75 | 0.90 |
| 120 | 0.5 | 0.5625 | 1.625 | 0.54 | 0.55 | 1.04 | 1.28 |
| 126 | 0.625 | 0.625 | 2.5625 | 0.63 | 0.63 | 1.50 | 1.93 |
| 132 | 0.75 | 0.875 | 3.5 | 0.82 | 0.85 | 2.06 | 2.65 |
| 138 | 0.75 | 1.25 | 4.8125 | 1.04 | 1.14 | 2.86 | 3.65 |
| 144 | 0.75 | 1.4375 | 5.8125 | 1.15 | 1.29 | 3.41 | 4.39 |
| 150 | 0.75 | 1.6875 | 7.125 | 1.30 | 1.49 | 4.14 | 5.36 |
| 156 | 0.875 | 2.25 | 8.25 | 1.68 | 1.96 | 4.96 | 6.30 |
| 162 | 0.875 | 2.5 | 9.75 | 1.83 | 2.16 | 5.77 | 7.39 |
| 168 | 0.875 | 2.875 | 11 | 2.05 | 2.45 | 6.54 | 8.36 |

### Table A - 1. Bonneville Unit 5 existing runner blade gaps

| | FLAT (As Measured) | MID (As Measured) | STEEP (As Measured) | CONDITION #1 | CONDITION #2 | CONDITION #3 | CONDITION #4 |
|---|---|---|---|---|---|---|---|
| | Blade Angle | Blade Angle | Blade Angle | Blade Angle | Blade Angle | Blade Angle | Blade Angle |
| | 5.502 | 18.932 | 33.702 | 13.4 | 16.1 | 25.6 | 28.9 |
| **Distance from Leading Edge** (inches) | **HUB Gap** (inches) | **HUB Gap** (inches) | **HUB Gap** (inches) | **HUB Gap** (inches) | **HUB Gap** (inches) | **HUB Gap** (inches) | **HUB Gap** (inches) |
| 0 | 11.5625 | 8.375 | 3.125 | 9.69 | 9.05 | 6.00 | 4.83 |
| 4 | 9.25 | 6.75 | 2.1875 | 7.78 | 7.28 | 4.69 | 3.67 |
| 8 | 6.75 | 4.9375 | 1.3125 | 5.68 | 5.32 | 3.30 | 2.49 |
| 12 | 4.5 | 3.3125 | 0.625 | 3.80 | 3.56 | 2.10 | 1.50 |
| 16 | 2.75 | 2.25 | 0.4375 | 2.46 | 2.36 | 1.43 | 1.03 |
| 20 | 1.5 | 1.5 | 0.4375 | 1.50 | 1.50 | 1.02 | 0.78 |
| 24 | 0.875 | 1 | 0.5 | 0.95 | 0.97 | 0.77 | 0.66 |
| 27 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| 31 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 |
| **Distance from Trailing Edge** (inches) | **HUB Gap** (inches) | **HUB Gap** (inches) | **HUB Gap** (inches) | **HUB Gap** (inches) | **HUB Gap** (inches) | **HUB Gap** (inches) | **HUB Gap** (inches) |
| 0 | 6.5 | 4.0625 | 0.3125 | 5.07 | 4.58 | 2.37 | 1.53 |
| 4 | 6 | 3.75 | 0.5625 | 4.68 | 4.22 | 2.31 | 1.60 |
| 8 | 5.5 | 3.3125 | 0.625 | 4.21 | 3.77 | 2.10 | 1.50 |
| 12 | 4.375 | 2.6875 | 0.5 | 3.38 | 3.04 | 1.70 | 1.21 |
| 16 | 3.375 | 2.3125 | 0.5 | 2.75 | 2.54 | 1.49 | 1.09 |
| 20 | 2.4375 | 1.5 | 0.5 | 1.89 | 1.70 | 1.05 | 0.83 |
| 24 | 1.75 | 1.375 | 0.5 | 1.53 | 1.45 | 0.98 | 0.78 |
| 28 | 1.25 | 0.9375 | 0.4375 | 1.07 | 1.00 | 0.71 | 0.60 |
| 30 | 1 | 0.875 | 0.4375 | 0.93 | 0.90 | 0.68 | 0.58 |

**Table A - 2. Measured gaps between the blade and discharge ring of Bonneville Unit 6 with Minimum Gap Runner installed**

| | FLAT (As Measured) | STEEP (As Measured) | CONDITION #1 | CONDITION #2 | CONDITION #3 | CONDITION #4 |
|---|---|---|---|---|---|---|
| | Blade Angle | Blade Angle | Blade Angle | Blade Angle | Blade Angle | Blade Angle |
| | 16.01 | 31.21 | 16.1 | 16.3 | 24.2 | 27.6 |
| Distance from Leading Edge (inches) | Measured Gap (inches) | Measured Gap (inches) | Measured Gap (inches) | Measured Gap (inches) | Measured Gap (inches) | Measured Gap (inches) |
| 0 | 0.25 | 3.375 | 0.27 | 0.31 | 1.93 | 2.63 |
| 4 | 0.23 | 2.5 | 0.25 | 0.28 | 1.45 | 1.96 |
| 8 | 0.21 | 1.5 | 0.22 | 0.24 | 0.91 | 1.19 |
| 12 | 0.20 | 0.875 | 0.20 | 0.21 | 0.56 | 0.71 |
| 16 | 0.18 | 0.375 | 0.18 | 0.18 | 0.28 | 0.33 |
| 20 | 0.16 | 0.25 | 0.16 | 0.16 | 0.21 | 0.23 |
| 24 | 0.14 | 0.1875 | 0.14 | 0.14 | 0.17 | 0.18 |
| 28 | 0.125 | 0.1875 | 0.13 | 0.13 | 0.16 | 0.17 |
| 32 | 0.125 | 0.125 | 0.13 | 0.13 | 0.13 | 0.13 |
| 91.25 | 0.125 | 0.125 | 0.13 | 0.13 | 0.13 | 0.13 |
| 95.25 | 0.125 | 0.1875 | 0.13 | 0.13 | 0.16 | 0.17 |
| 99.25 | 0.125 | 0.25 | 0.13 | 0.13 | 0.19 | 0.22 |
| 103.25 | 0.125 | 0.375 | 0.13 | 0.13 | 0.26 | 0.32 |
| 107.25 | 0.125 | 0.625 | 0.13 | 0.13 | 0.39 | 0.51 |
| 111.25 | 0.125 | 0.75 | 0.13 | 0.14 | 0.46 | 0.60 |
| 115.25 | 0.15 | 1 | 0.15 | 0.16 | 0.61 | 0.80 |
| 119.25 | 0.17 | 1.5 | 0.17 | 0.19 | 0.89 | 1.18 |
| 123.25 | 0.19 | 1.875 | 0.20 | 0.22 | 1.10 | 1.47 |
| 127.25 | 0.21 | 2.25 | 0.22 | 0.25 | 1.31 | 1.77 |
| 131.25 | 0.23 | 2.875 | 0.24 | 0.28 | 1.65 | 2.25 |
| 135.25 | 0.25 | 3.25 | 0.27 | 0.31 | 1.87 | 2.54 |
| 139.25 | 0.375 | 3.375 | 0.39 | 0.43 | 1.99 | 2.66 |

* The minimum gap runner does not have a measurable gap between the blade and the hub

## Table A - 3.  The Dalles Unit 9

| | FLAT (As Measured) | STEEP (As Measured) | CONDITION #1 | CONDITION #2 | CONDITION #3 | CONDITION #4 |
|---|---|---|---|---|---|---|
| | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** |
| | 19.53 | 35.23 | 20.0 | 23.5 | 27.4 | 31.3 |
| **Distance from Leading Edge (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** |
| 0 | 5.500 | 0.188 | 5.341 | 4.172 | 2.844 | 1.516 |
| 6 | 4.000 | 0.188 | 3.886 | 3.047 | 2.094 | 1.141 |
| 12 | 2.500 | 0.188 | 2.431 | 1.922 | 1.344 | 0.766 |
| 18 | 1.625 | 0.188 | 1.582 | 1.266 | 0.906 | 0.547 |
| 24 | 1.125 | 0.188 | 1.097 | 0.891 | 0.656 | 0.422 |
| 30 | 0.750 | 0.188 | 0.733 | 0.609 | 0.469 | 0.328 |
| 36 | 0.500 | 0.188 | 0.491 | 0.422 | 0.344 | 0.266 |
| 42 | 0.375 | 0.188 | 0.369 | 0.328 | 0.281 | 0.234 |
| 48 | 0.188 | 0.188 | 0.188 | 0.188 | 0.188 | 0.188 |
| 89.25 | 0.188 | 0.188 | 0.188 | 0.188 | 0.188 | 0.188 |
| 95.25 | 0.500 | 0.188 | 0.491 | 0.422 | 0.344 | 0.266 |
| 101.25 | 0.750 | 0.188 | 0.733 | 0.609 | 0.469 | 0.328 |
| 107.25 | 1.250 | 0.188 | 1.218 | 0.984 | 0.719 | 0.453 |
| 113.25 | 1.750 | 0.188 | 1.703 | 1.359 | 0.969 | 0.578 |
| 119.25 | 2.750 | 0.188 | 2.673 | 2.109 | 1.469 | 0.828 |
| 125.25 | 3.500 | 0.188 | 3.401 | 2.672 | 1.844 | 1.016 |
| 131.25 | 4.500 | 0.188 | 4.371 | 3.422 | 2.344 | 1.266 |
| 137.25 | 5.500 | 0.188 | 5.341 | 4.172 | 2.844 | 1.516 |
| 143.25 | 6.750 | 0.188 | 6.553 | 5.109 | 3.469 | 1.828 |
| 149.25 | 7.750 | 0.188 | 7.523 | 5.859 | 3.969 | 2.078 |
| 155.25 | 9.250 | 0.188 | 8.978 | 6.984 | 4.719 | 2.453 |
| 161.25 | 10.500 | 0.313 | 10.194 | 7.953 | 5.406 | 2.859 |
| 167.25 | 12.000 | 0.313 | 11.649 | 9.078 | 6.156 | 3.234 |
| **Distance from Leading Edge** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) |
| 0 | 0.188 | 4.250 | 0.309 | 1.203 | 2.219 | 3.234 |
| 6 | 0.188 | 3.125 | 0.276 | 0.922 | 1.656 | 2.391 |
| 12 | 0.188 | 2.500 | 0.257 | 0.766 | 1.344 | 1.922 |
| 18 | 0.188 | 0.938 | 0.210 | 0.375 | 0.563 | 0.750 |
| 24 | 0.188 | 0.875 | 0.208 | 0.359 | 0.531 | 0.703 |

### Table A - 3. The Dalles Unit 9

| | FLAT (As Measured) | STEEP (As Measured) | CONDITION #1 | CONDITION #2 | CONDITION #3 | CONDITION #4 |
|---|---|---|---|---|---|---|
| | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** |
| | 19.53 | 35.23 | 20.0 | 23.5 | 27.4 | 31.3 |
| **Distance from Trailing Edge** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) |
| 0 | 0.188 | 2.688 | 0.263 | 0.813 | 1.438 | 2.063 |
| 6 | 0.188 | 2.375 | 0.253 | 0.734 | 1.281 | 1.828 |
| 12 | 0.188 | 1.875 | 0.238 | 0.609 | 1.031 | 1.453 |
| 18 | 0.188 | 1.500 | 0.227 | 0.516 | 0.844 | 1.172 |
| 24 | 0.188 | 1.000 | 0.212 | 0.391 | 0.594 | 0.797 |
| 30 | 0.188 | 0.688 | 0.203 | 0.313 | 0.438 | 0.563 |

### Table A - 4. John Day Unit 9

Flat Overtravel Measurements could not be found

| | FLAT (As Measured) | STEEP (As Measured) | CONDITION #1 | CONDITION #2 | CONDITION #3 | CONDITION #4 |
|---|---|---|---|---|---|---|
| | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** |
| | 17.97 | 35.27 | 18.5 | 22.3 | 26.6 | 30.9 |
| **Distance from Leading Edge (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** |
| 0 | | 5.750 | 0.166 | 1.438 | 2.875 | 4.313 |
| 6 | | 4.750 | 0.137 | 1.188 | 2.375 | 3.563 |
| 12 | | 3.063 | 0.089 | 0.766 | 1.531 | 2.297 |
| 18 | | 2.625 | 0.076 | 0.656 | 1.313 | 1.969 |
| 24 | | 2.000 | 0.058 | 0.500 | 1.000 | 1.500 |
| 30 | | 1.875 | 0.054 | 0.469 | 0.938 | 1.406 |
| 36 | | 1.125 | 0.033 | 0.281 | 0.563 | 0.844 |
| 42 | | 0.750 | 0.022 | 0.188 | 0.375 | 0.563 |
| 48 | | 0.500 | 0.014 | 0.125 | 0.250 | 0.375 |
| 54 | | 0.250 | 0.007 | 0.063 | 0.125 | 0.188 |
| 110 | | 0.250 | 0.007 | 0.063 | 0.125 | 0.188 |
| 116 | | 0.313 | 0.009 | 0.078 | 0.156 | 0.234 |
| 122 | | 0.750 | 0.022 | 0.188 | 0.375 | 0.563 |
| 128 | | 1.250 | 0.036 | 0.313 | 0.625 | 0.938 |

## Table A - 4. John Day Unit 9

Flat Overtravel Measurements could not be found

| | FLAT (As Measured) | STEEP (As Measured) | CONDITION #1 | CONDITION #2 | CONDITION #3 | CONDITION #4 |
|---|---|---|---|---|---|---|
| | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** |
| | 17.97 | 35.27 | 18.5 | 22.3 | 26.6 | 30.9 |
| 134 | | 1.875 | 0.054 | 0.469 | 0.938 | 1.406 |
| 140 | | 2.563 | 0.074 | 0.641 | 1.281 | 1.922 |
| 146 | | 3.500 | 0.101 | 0.875 | 1.750 | 2.625 |
| 152 | | 4.500 | 0.130 | 1.125 | 2.250 | 3.375 |
| 158 | | 5.313 | 0.154 | 1.328 | 2.656 | 3.984 |
| 164 | | 6.938 | 0.201 | 1.734 | 3.469 | 5.203 |
| 170 | | 8.125 | 0.235 | 2.031 | 4.063 | 6.094 |
| 176 | | 9.250 | 0.267 | 2.313 | 4.625 | 6.938 |
| 182 | | 10.250 | 0.296 | 2.563 | 5.125 | 7.688 |
| 188 | | 11.438 | 0.331 | 2.859 | 5.719 | 8.578 |
| 194 | | 12.375 | 0.358 | 3.094 | 6.188 | 9.281 |
| **Dist from Leading Edge** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) |
| 0 | | 0.125 | 0.004 | 0.031 | 0.063 | 0.094 |
| 6 | | 0.125 | 0.004 | 0.031 | 0.063 | 0.094 |
| 12 | | 0.125 | 0.004 | 0.031 | 0.063 | 0.094 |
| 18 | | 0.125 | 0.004 | 0.031 | 0.063 | 0.094 |
| 24 | | 0.125 | 0.004 | 0.031 | 0.063 | 0.094 |
| **Dist from Trailing Edge** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) |
| 0 | | 0.125 | 0.004 | 0.031 | 0.063 | 0.094 |
| 6 | | 0.125 | 0.004 | 0.031 | 0.063 | 0.094 |
| 12 | | 0.125 | 0.004 | 0.031 | 0.063 | 0.094 |
| 18 | | 0.125 | 0.004 | 0.031 | 0.063 | 0.094 |
| 24 | | 0.125 | 0.004 | 0.031 | 0.063 | 0.094 |

**Table A - 5.  McNary Unit 9**

|  | **FLAT (As Measured)** | **STEEP (As Measured)** | **CONDITION #1** | **CONDITION #2** | **CONDITION #3** | **CONDITION #4** |
|---|---|---|---|---|---|---|
|  | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** | **Blade Angle** |
|  | 16.5 | 33 | 17.0 | 20.6 | 24.8 | 28.9 |
| **Distance from Leading Edge (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** | **TIP Gap (inches)** |
| 0 | 0.500 | 3.500 | 0.590 | 1.250 | 2.000 | 2.750 |
| 6 | 0.375 | 2.500 | 0.439 | 0.906 | 1.438 | 1.969 |
| 12 | 0.313 | 1.625 | 0.352 | 0.641 | 0.969 | 1.297 |
| 18 | 0.313 | 1.125 | 0.337 | 0.516 | 0.719 | 0.922 |
| 24 | 0.375 | 0.750 | 0.386 | 0.469 | 0.563 | 0.656 |
| 30 | 0.375 | 0.500 | 0.379 | 0.406 | 0.438 | 0.469 |
| 36 | 0.375 | 0.250 | 0.371 | 0.344 | 0.313 | 0.281 |
| **Dist from Trailing Edge** (inches) | **TIP Gap** (inches) | **TIP Gap** (inches) | **TIP Gap** (inches) | **TIP Gap** (inches) | **TIP Gap** (inches) | **TIP Gap** (inches) |
| 0 | 0.750 | 9.250 | 1.005 | 2.875 | 5.000 | 7.125 |
| 6 | 0.625 | 8.000 | 0.846 | 2.469 | 4.313 | 6.156 |
| 12 | 0.625 | 7.000 | 0.816 | 2.219 | 3.813 | 5.406 |
| 18 | 0.500 | 6.000 | 0.665 | 1.875 | 3.250 | 4.625 |
| 24 | 0.438 | 4.750 | 0.567 | 1.516 | 2.594 | 3.672 |
| 30 | 0.375 | 3.750 | 0.476 | 1.219 | 2.063 | 2.906 |
| 36 | 0.375 | 2.875 | 0.450 | 1.000 | 1.625 | 2.250 |
| **Dist from Trailing Edge** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) |
| 0 | 1.250 | 0.250 | 1.220 | 1.000 | 0.750 | 0.500 |
| 6 | 0.375 | 0.250 | 0.371 | 0.344 | 0.313 | 0.281 |
| 12 | 0.313 | 0.250 | 0.311 | 0.297 | 0.281 | 0.266 |
| 18 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| **Dist from Trailing Edge** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) | **Hub Gap** (inches) |
| 0 | 3.750 | 1.000 | 3.668 | 3.063 | 2.375 | 1.688 |
| 6 | 2.500 | 0.500 | 2.440 | 2.000 | 1.500 | 1.000 |
| 12 | 1.750 | 0.500 | 1.713 | 1.438 | 1.125 | 0.813 |
| 18 | 1.125 | 0.437 | 1.104 | 0.953 | 0.781 | 0.609 |

### A.3.3 Wicket Gate Openings

The wicket gates are calibrated prior to index testing by numbering each of the gates while the turbine is unwatered. The gates are then opened to about 75 percent servo stroke. The clearance between each gate pair and the distributor height is measured. The average clearance is multiplied by the distributor height for each gate pair to determine the average opening. The average wicket gate pair openings are then measured at nominal 10 percent intervals from 10 to 100 percent servo stroke. The results of these measurements are used to determine a curve fit equation for the gate opening versus servo stroke. Figure A - 22 shows how the measurements were acquired for the calibration equation.

**Figure A - 22. Example of measuring the wicket gate opening**

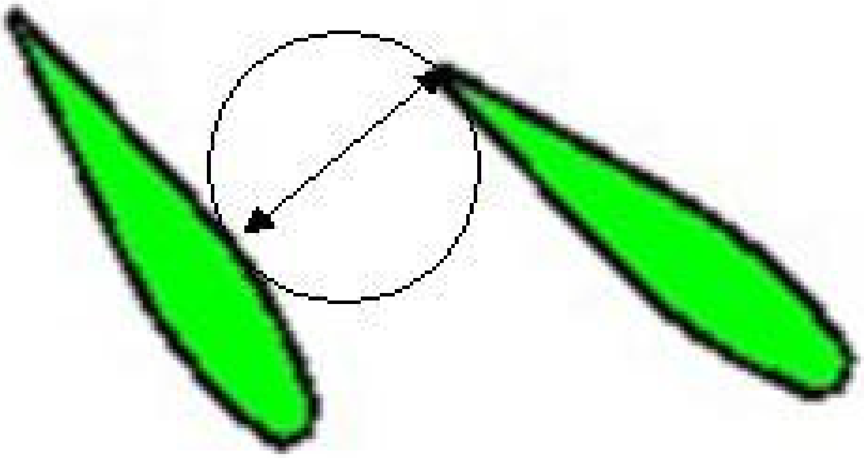


**Figure A - 23. Plan view of wicket gate opening measurement location**

## Table A - 6.  Example set of wicket gate opening measurements from a calibration

Bonneville Unit 6 Index Test — Wicket Gate Calibration — July 1999

| Gate Pair | Distributor Height (in.) | Minimum Opening Top (in.) | Minimum Opening Center (in.) | Minimum Opening Bottom (in.) | Average* Opening (in.) | Average Area (in.$^2$) | |
|---|---|---|---|---|---|---|---|
| A-B | 114.007 | 31.504 | 31.247 | 33.421 | 31.376 | 3,577.03 | |
| B-C | 114.037 | 31.529 | 31.401 | 33.505 | 31.465 | 3,588.17 | |
| C-D | 114.000 | 31.326 | 31.089 | 33.369 | 31.208 | 3,557.66 | |
| D-E | 114.038 | 31.542 | 31.195 | 33.578 | 31.369 | 3,577.20 | |
| E-F | 114.028 | 31.434 | 31.267 | 33.426 | 31.351 | 3,574.83 | |
| F-G | 114.033 | 31.420 | 31.102 | 33.460 | 31.261 | 3,564.79 | |
| G-H | 114.020 | 31.351 | 31.212 | 33.342 | 31.282 | 3,566.72 | |
| H-I | 114.004 | 31.355 | 31.216 | 33.484 | 31.286 | 3,566.67 | |
| I-J | 114.015 | 31.392 | 31.148 | 33.463 | 31.270 | 3,565.25 | |
| J-K | 114.015 | 31.448 | 31.280 | 33.389 | 31.364 | 3,575.97 | |
| K-L | 114.000 | 31.559 | 31.497 | 33.630 | 31.528 | 3,594.19 | |
| L-M | 114.009 | 31.460 | 30.961 | 33.256 | 31.211 | 3,558.28 | |
| M-N | 114.002 | 31.379 | 31.142 | 33.482 | 31.261 | 3,563.76 | |
| N-O | 114.011 | 31.340 | 31.116 | 33.425 | 31.228 | 3,560.34 | |
| O-P | 114.022 | 31.359 | 31.358 | 33.484 | 31.359 | 3,575.56 | |
| P-Q | 114.012 | 31.349 | 31.362 | 33.416 | 31.356 | 3,574.90 | |
| Q-R | 114.024 | 31.418 | 31.268 | 33.395 | 31.343 | 3,573.85 | <=== SELECTED PAIR |
| R-S | 114.036 | 31.375 | 31.211 | 33.534 | 31.293 | 3,568.53 | |
| S-T | 114.031 | 31.361 | 31.116 | 33.432 | 31.239 | 3,562.16 | |
| T-A | 114.026 | 31.507 | 31.304 | 33.471 | 31.405 | 3,581.02 | |
| | | | | | | 3,571.34 | <=== Average |

| Governor Reading | Gate Ring Reading | Actual Machinist Scale Reading | Machinist Scale Reading inches | Servo Stroke inches | Servo Stroke % |
|---|---|---|---|---|---|
| squeeze | 0 | 53/64" | 0.83 | 0 | 0.00 |
| zero | | 1 0/64" | 1.00 | 0.17 | 0.46 |
| 10.1 | 1.05 | 5 4/64" | 5.06 | 4.23 | 11.37 |
| 17.5 | 1.85 | 7 54/64" | 7.84 | 6.84 | 18.37 |
| 28.0 | 2.90 | 11 52/64" | 11.81 | 10.81 | 29.03 |
| 35.5 | 3.78 | 14 52/64" | 14.81 | 13.81 | 37.08 |
| 46.6 | 4.73 | 18 52/64" | 18.81 | 17.81 | 47.82 |
| 59.5 | 6.05 | 23 53/64" | 23.83 | 22.83 | 61.28 |
| 67.5 | 6.85 | 26 53/64" | 26.83 | 25.83 | 69.34 |
| 78.0 | 7.90 | 30 52/64" | 30.81 | 29.81 | 80.03 |
| 89.0 | 8.95 | 34 53/64" | 34.83 | 33.83 | 90.81 |
| 99.8 | 10.00 | 38 55/64" | 38.86 | 37.86 | 101.64 |

| Wicket Gate Opening Top inches | Wicket Gate Opening Middle inches | Wicket Gate Opening Bottom inches | Wicket Gate Opening Average* inches |
|---|---|---|---|
| ----- | ----- | ----- | 0 |
| ----- | ----- | ----- | 0 |
| 3.997 | 3.991 | 3.997 | 3.994 |
| 7.165 | 7.135 | 7.400 | 7.150 |
| 11.660 | 11.672 | 12.293 | 11.666 |
| 15.150 | 15.121 | 16.069 | 15.136 |
| 19.742 | 19.688 | 21.126 | 19.715 |
| 25.230 | 25.134 | 27.051 | 25.182 |
| 28.365 | 28.252 | 30.242 | 28.309 |
| 32.316 | 32.247 | 34.290 | 32.282 |
| 35.881 | 35.890 | 37.774 | 35.886 |
| 39.059 | 39.010 | 40.636 | 39.035 |

* tapered gate, average of Top & Middle Used

### A.3.4 Head Measurement Improvements

Measurement of the head on a turbine is an important parameter in precise operational control of the Kaplan unit. The head measurement is one of the three parameters in a 3-D cam (blade position, gate position, and operating head). The plant original head measurement systems are obsolete. Modern instrumentation is capable of measuring a difference in water surface elevations at two significantly spatially separated locations within an error of only a couple of inches, regardless of the total head being measured. However, operation of adjacent units or civil works features can cause fluctuations in water surface elevations that can greatly increase the uncertainty of an individual measurement. Consequently, head measurement on each generating unit is needed to minimize uncertainty. A program to improve the head measurements at the Columbia and Snake River powerhouses has been under taken by the Corps funded from another program. This improvement in head measurement greatly reduces the uncertainty of prototype turbine operation assuring optimum geometric positions. The following Figure A - 24 shows the potential improvement in head measurement accuracy between a single plant head measurement of tailwater and a direct measurement of tailwater at the turbine in operation. A similar uncertainty exists for the pool elevation measurements. This uncertainty is greatly increased during spill conditions, which affect both the pool elevations and the tailwater elevations.

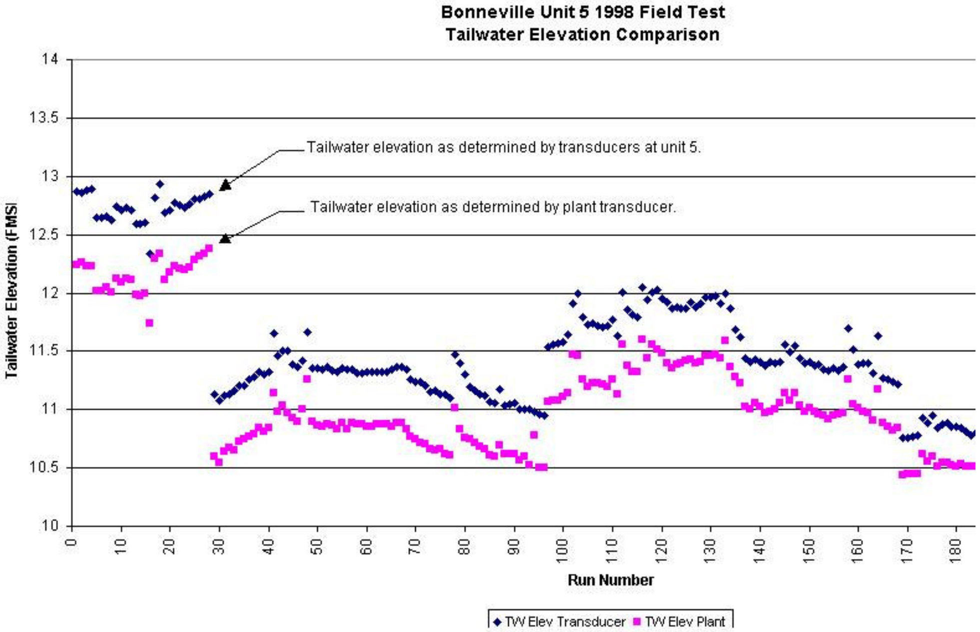


**Figure A - 24. Example of tailwater elevation measurement uncertainty-plant to individual unit**

### A.3.5 Governor Adjustments

Over time the mechanical components of the governors go out of adjustment due to wear, maladjustment, or lack of maintenance. As a result of index testing and biological testing the need to have the governors operate the turbine unit within original design parameters was found to be difficult to accomplish. In general it was found that perception of the operating geometry of the turbine was not consistent with actual operating geometry. Many of the control feed back loop features were adjusted to allow very large dead bands to eliminate regularly reoccurring alarms and emergency shut downs of the units, which were occurring unnecessarily due to unadjustable wear and tear (no more adjustment left in the mechanism). It was found that resetting the adjustment bands calibration, repair or replacement of minor parts or electronics could return an existing unit to more precise operation. An example of operational geometric departure caused by a lost lock washer on a 3-D cam adjustment nut is shown in Figure A - 25. This lost lock washer permitted normal operation of the turbine over a limited range and reset the blade gate relationship when a enough torque rotated the linkage without making the correct adjustment (slipped). The electronics reported the correct positioning, however, the mechanical component had not actually moved correctly. This error could only be detected by performing a calibration of the unit and comparing desired results to measured results.

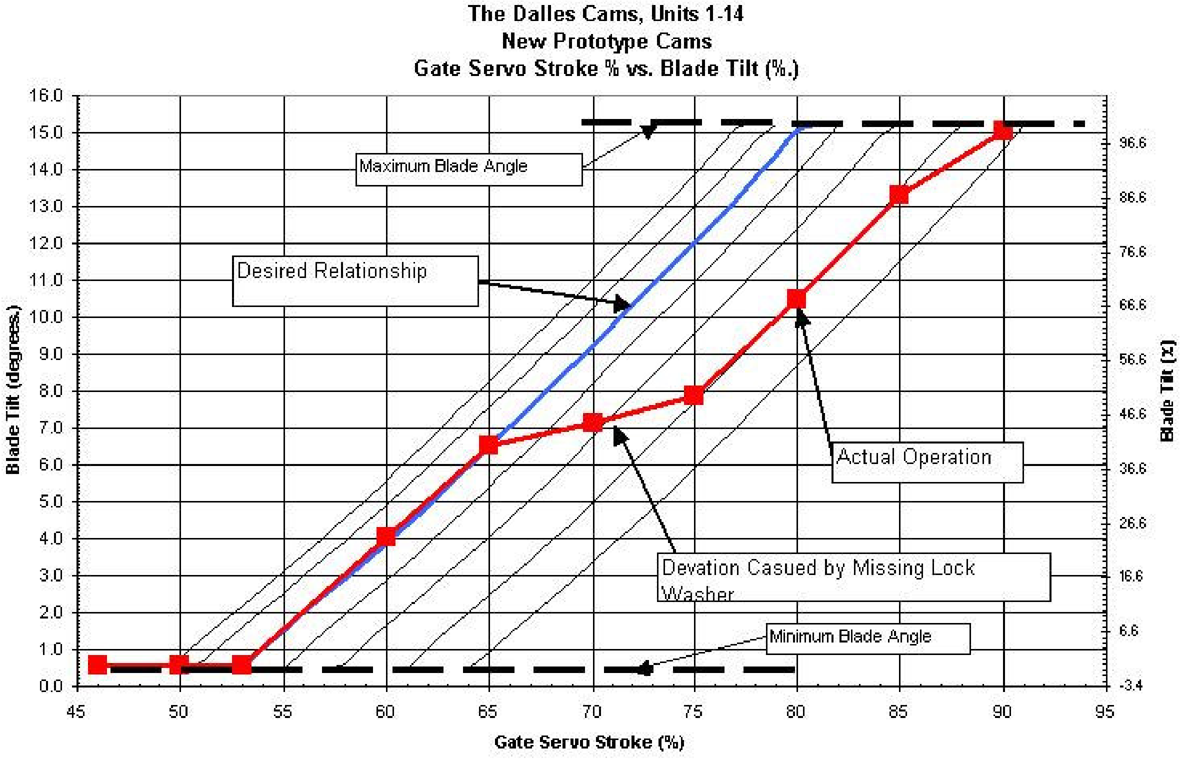


**Figure A - 25. Example of 3-D cam operational error on on cam operation**

## A.4 One-Percent Operating Limits

The development of the one percent operating limits is based on the best information that is available at the time the tables are prepared. The following paragraphs show the resulting information required for the one percent operating limit tables for the entire operating head range. The field index test data, previous model test data, and previous field measurements are consolidated into consistent operational information. Considerable engineering effort is required to adjust and consolidate the information into expected turbine performance curves, flow tables, and geometric cam curves that result in the one percent operating limit tables. These tables are developed for both with and without fish diversion devices installed on a particular turbine family at a particular project. Examples of these products are provided for one specific project and the final one percent operating limit tables from various existing projects are provided in A.4.4 below.

### A.4.1 Sample Performance Curves

The following is a sample performance curve family for Lower Monumental Units 4-6. These families of curves must be made for with and without fish diversion devices installed. Figure A - 26 show the without screens condition and Figure A - 27 shows the STS screens installed performance. A comparison of the turbine performance under the two operating conditions shows the performance difference.

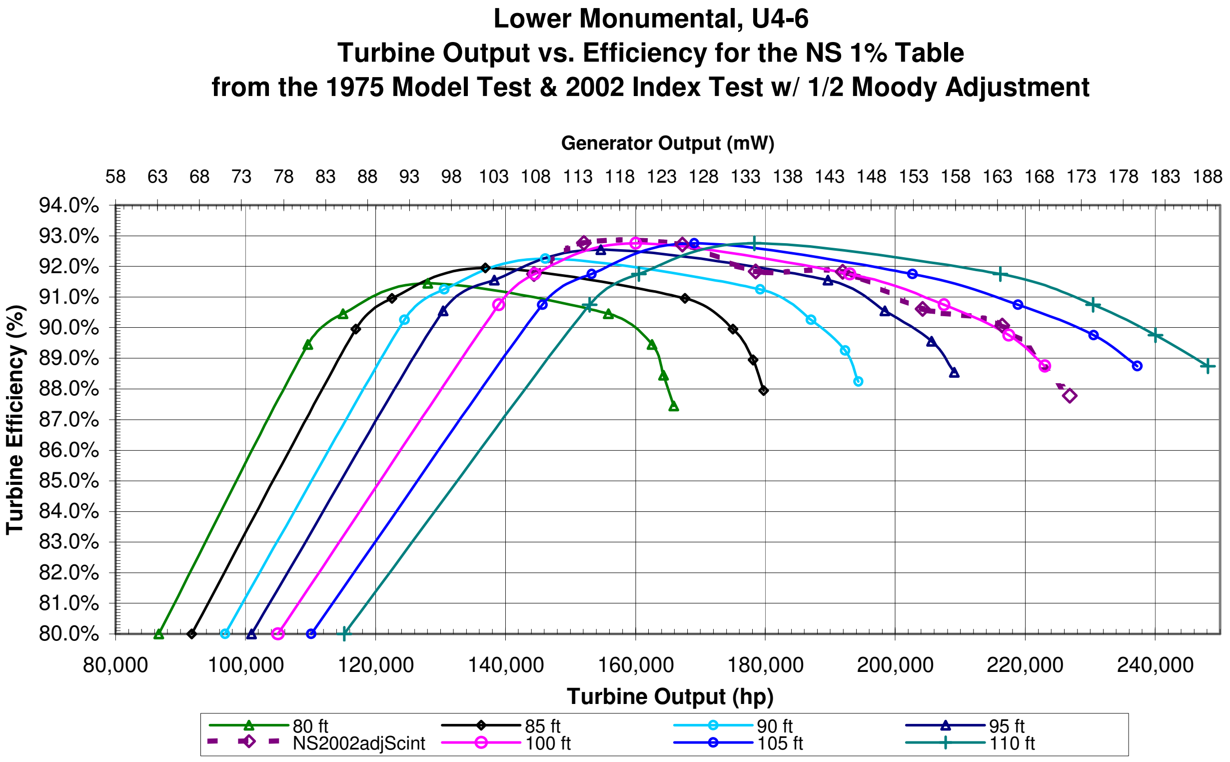


**Figure A - 26. Example family of performance curves for no screens installed**

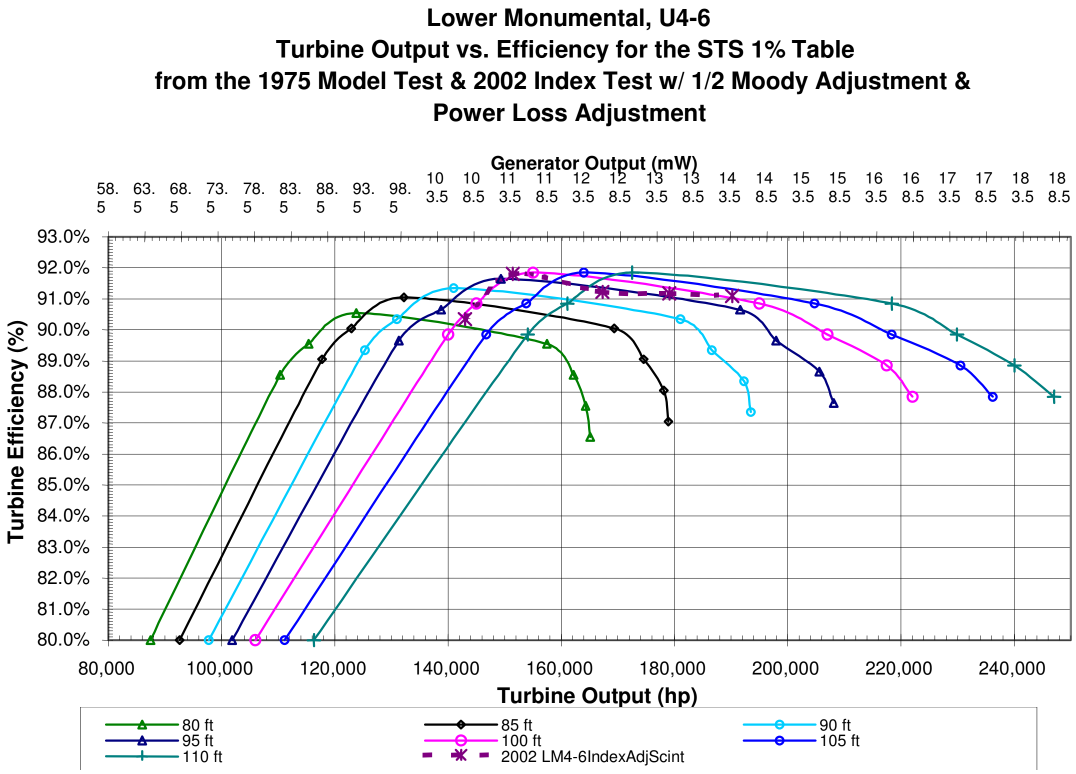


**Figure A - 27. Example family of turbine performance curves with STS screens installed**

## A.4.2 Sample Flow Table

As part of the information needed for the control system and to account for project and unit flow, a set of turbine discharge tables and curves are needed. These tables and curves are input to the GDACS system to report automatically on the flow conditions and capability of a particular project. Examples of the flow graphs are provided below. The flow tables are much more extensive and allow detailed evaluation of flow at a project. Figure A - 28 shows the graph of a without screens condition and Figure A - 29 shows a graph of with STS screens installed condition. A comparison of the graphs indicates the change in flow for the two operating conditions.

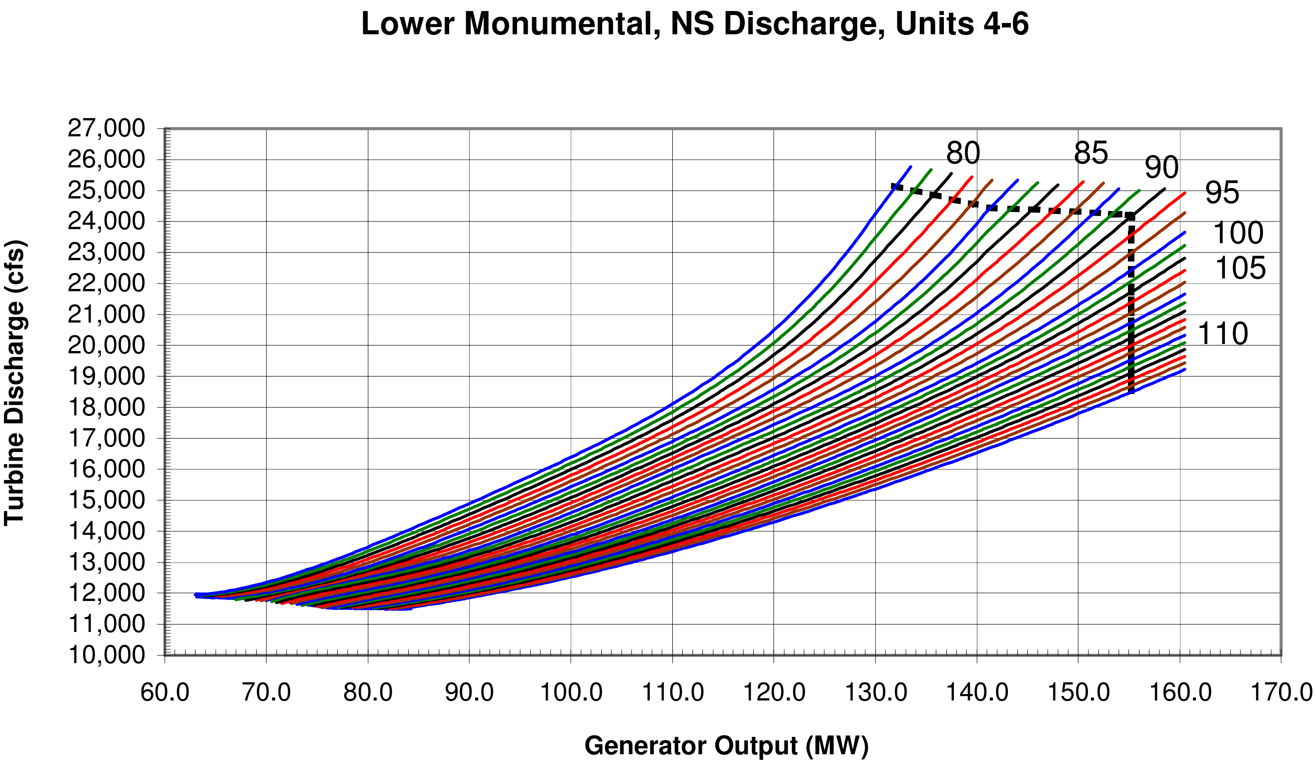


Figure A - 28. Example turbine discharge graph without screens installed

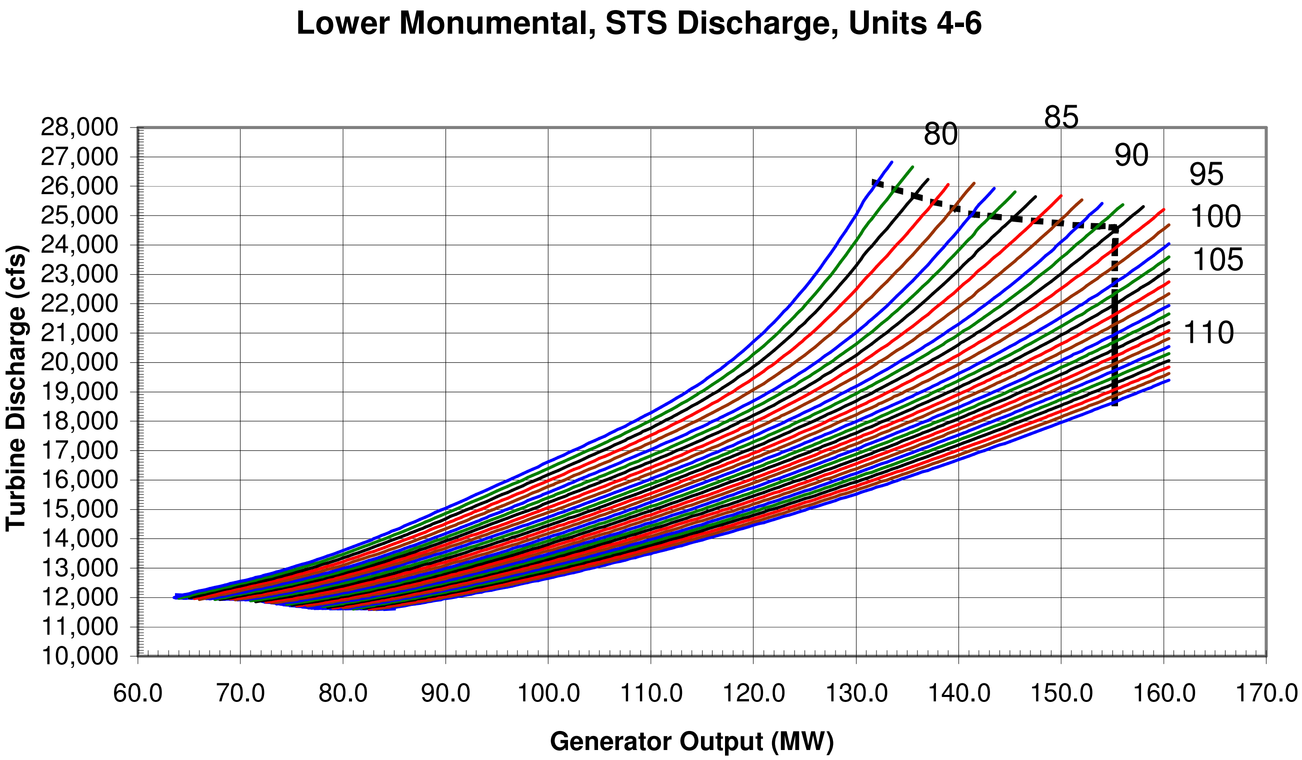


Figure A - 29. Example turbine discharge graph with STS fish screens installed

## A.4.3 Sample On Cam Family of Curves

The individual turbine electronic control units require the geometrical positioning of the turbine runner blade angle to the wicket gate position. The turbine runner blades follow the wicket positions that are dictated by the power requirements requested of the turbine to produce. These curves are input directly into the control system of a turbine as data tables. These data tables are adjusted for each turbine based upon the particular units calibration values. The involvement of the TSP in the need for operational improvements for fish passage improvements has resulted in much more detailed and precise tables for maintaining the correct geometrical positioning of each turbine unit. Figure A - 30 and Figure A - 31 are examples of the graphs of the actual operating tables for Lower Monumental Units 4-6. A comparison of the two families shows the difference in the operation geometry required for the two conditions of operation.

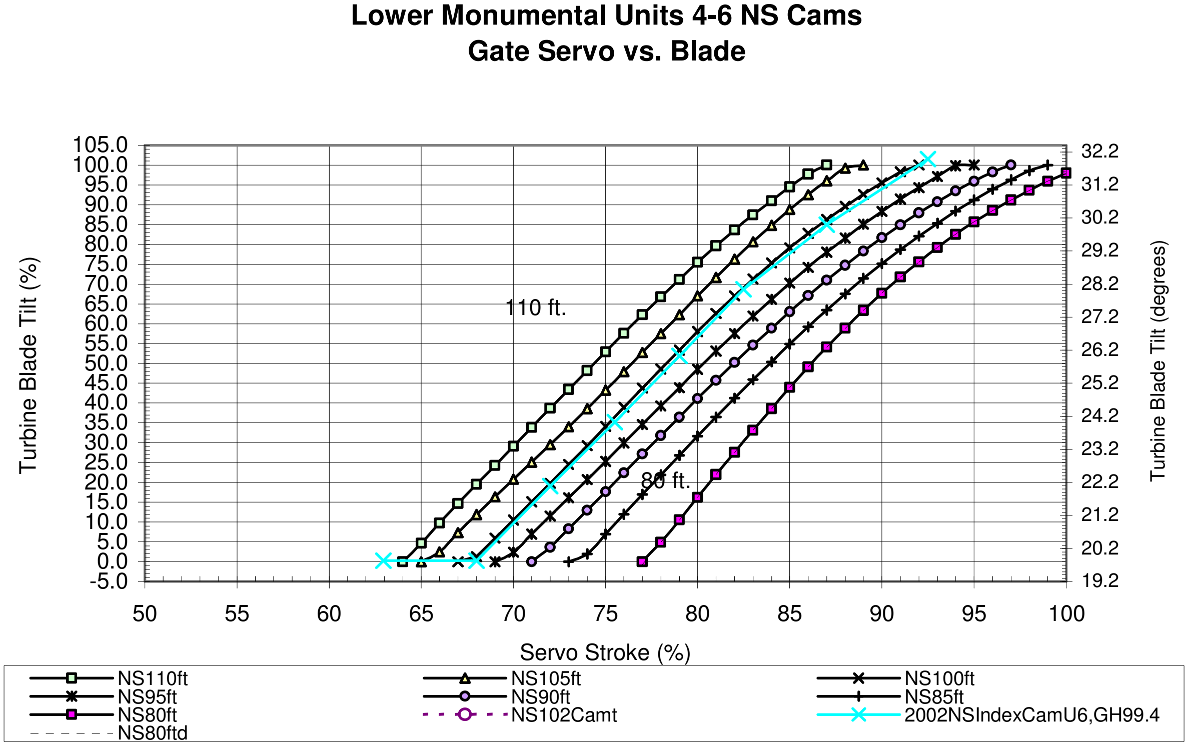


Figure A - 30. On cam table graph of the no screen operating geometry

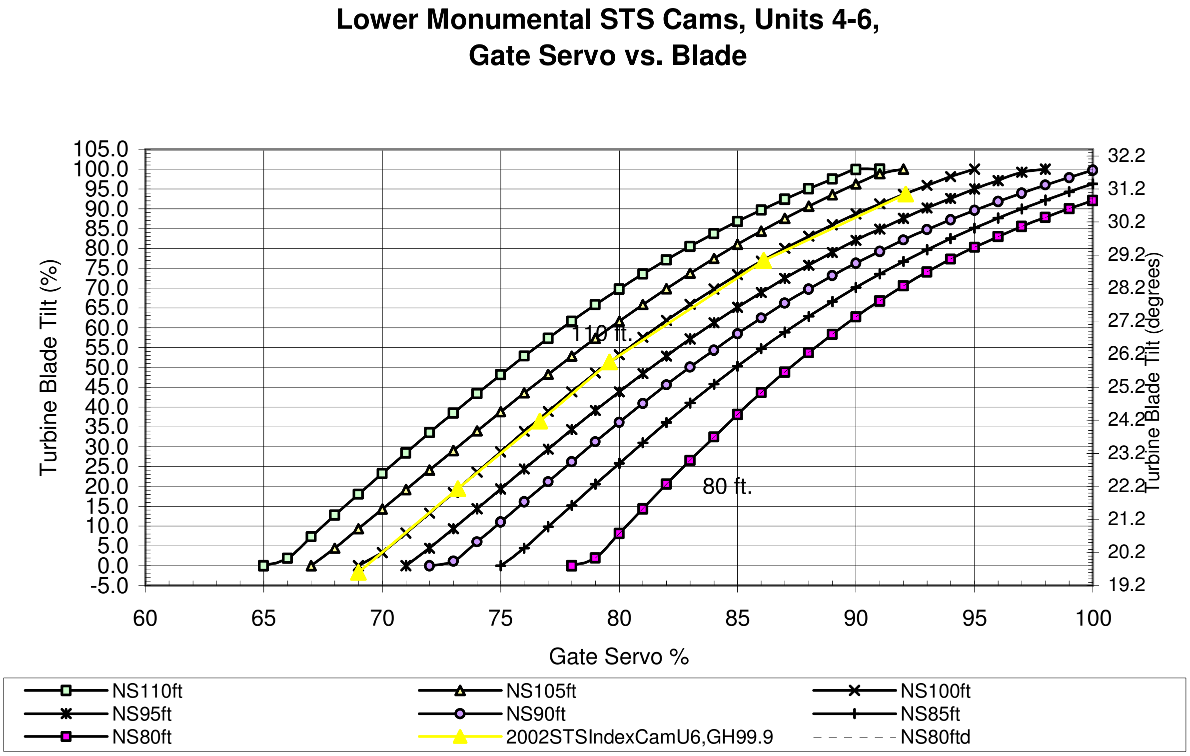


**Figure A - 31. On cam table graph of the with STS screens operating geometry**

## A.4.4 One-Percent Operating Tables

The following tables are an example of the one-percent efficiency turbine operating limitations of existing turbine design families in the Corps hydropower system. The tables were current at the time of publication but are subject to revisions based upon on going Index testing (tuning) and design investigations. The contents of this table is different than is contained in the current Fish Passage Plan (FPP) which only contains the power and flow limitations. The content of this table was developed through extensive coordination with the TSP team, the region and Corps operations staff. Much of the information establishes the actual limitations of the machines in addition to the one percent operating limitations. These other limitations identify operational constraints should operation be required other than within the one percent operational limitation band.

## A.4.4.1 Bonneville I Existing Units and MGR Units

### Without Fish Screens

**Table A - 7. One percent table for Bonneville Units 1 to 10 with no screens installed – new MGRs**

🟩 Maximum Power Output @ 1%

🟨 T = -0.9847GH + 71.148 Gross Head to Tailwater Based on CROHMS

**Bonneville, U1-10, New MG Runners, 1% Table with No Screens Installed**

Based on the 1999 U6 Index Test and the 1997 Model Hill Curve

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (%) | (ft) | (mW) |
| 35 | **13.2** | 5,678 | **90.3%** | **18.9** | 7,203 | **19.6** | 7412 | **23.6** | 9,019 | 31.8 | 12,960 | 36.68 | 62.1 |
| 36 | 13.4 | 5,615 | 90.6% | 19.5 | 7,205 | 20.3 | 7414 | 24.3 | 8,985 | 33.0 | 12,997 | 35.70 | 62.1 |
| 37 | 13.6 | 5,555 | 90.9% | 20.1 | 7,205 | 20.9 | 7414 | 25.0 | 8,951 | 34.1 | 13,028 | 34.71 | 62.1 |
| 38 | 13.9 | 5,499 | 91.1% | 20.7 | 7,204 | 21.5 | 7413 | 25.6 | 8,918 | 35.3 | 13,054 | 33.73 | 62.1 |
| 39 | 14.1 | 5,445 | 91.4% | 21.3 | 7,202 | 22.2 | 7412 | 26.3 | 8,886 | 36.4 | 13,076 | 32.74 | 62.1 |
| 40 | **14.3** | 5,394 | **91.7%** | **21.9** | 7,199 | **22.8** | 7409 | **26.9** | 8,854 | 37.6 | 13,093 | 31.76 | 62.1 |
| 41 | 14.6 | 5,355 | 91.8% | 22.5 | 7,201 | 23.6 | 7467 | 28.0 | 8,969 | 38.8 | 13,147 | 30.78 | 62.1 |
| 42 | 14.8 | 5,318 | 91.9% | 23.1 | 7,202 | 24.3 | 7521 | 29.1 | 9,077 | 40.0 | 13,197 | 29.79 | 62.1 |
| 43 | 15.1 | 5,282 | 92.1% | 23.6 | 7,203 | 25.1 | 7572 | 30.1 | 9,180 | 41.1 | 13,242 | 28.81 | 62.1 |
| 44 | 15.3 | 5,248 | 92.2% | 24.2 | 7,203 | 25.9 | 7620 | 31.2 | 9,278 | 42.3 | 13,284 | 27.82 | 62.1 |
| 45 | **15.6** | 5,216 | **92.3%** | **24.8** | 7,203 | **26.7** | 7666 | **32.3** | 9,370 | 43.5 | 13,322 | 26.84 | 62.1 |
| 46 | 15.8 | 5,164 | 92.4% | 25.4 | 7,210 | 27.2 | 7641 | 33.2 | 9,416 | 44.6 | 13,303 | 25.85 | 62.1 |
| 47 | 16.0 | 5,114 | 92.5% | 26.0 | 7,217 | 27.8 | 7618 | 34.1 | 9,459 | 45.7 | 13,280 | 24.87 | 62.1 |
| 48 | 16.1 | 5,067 | 92.7% | 26.6 | 7,223 | 28.3 | 7594 | 35.0 | 9,500 | 46.7 | 13,253 | 23.88 | 62.1 |
| 49 | 16.3 | 5,022 | 92.8% | 27.3 | 7,229 | 28.9 | 7572 | 36.0 | 9,539 | 47.8 | 13,222 | 22.90 | 62.1 |
| 50 | **16.5** | 4,978 | **92.9%** | **27.9** | 7,234 | **29.4** | 7550 | **36.9** | 9,575 | 48.8 | 13,188 | 21.91 | 62.1 |
| 51 | 16.9 | 4,981 | 93.0% | 28.5 | 7,241 | 30.0 | 7546 | 37.8 | 9,618 | 49.9 | 13,207 | 20.93 | 62.1 |
| 52 | 17.2 | 4,983 | 93.1% | 29.1 | 7,248 | 30.6 | 7542 | 38.4 | 9,577 | 51.0 | 13,222 | 19.94 | 62.1 |
| 53 | 17.5 | 4,985 | 93.1% | 29.7 | 7,254 | 31.2 | 7538 | 39.0 | 9,537 | 52.1 | 13,234 | 18.96 | 62.1 |
| 54 | 17.9 | 4,988 | 93.2% | 30.3 | 7,260 | 31.8 | 7533 | 39.7 | 9,499 | 53.1 | 13,242 | 17.97 | 62.1 |
| 55 | **18.2** | 4,990 | **93.3%** | **30.9** | 7,266 | **32.4** | 7529 | **41.6** | 9,768 | 54.2 | 13,248 | 16.99 | 62.1 |
| 56 | 18.6 | 5,002 | 93.3% | 31.5 | 7,269 | 33.1 | 7549 | 42.5 | 9,808 | 54.6 | 13,046 | 16.00 | 62.1 |
| 57 | 19.0 | 5,014 | 93.3% | 32.1 | 7,272 | 33.8 | 7569 | 43.4 | 9,846 | 54.9 | 12,841 | 15.02 | 62.1 |
| 58 | 19.3 | 5,026 | 93.4% | 32.7 | 7,274 | 34.4 | 7587 | 44.4 | 9,883 | 55.3 | 12,633 | 14.04 | 62.1 |
| 59 | 19.7 | 5,037 | 93.4% | 33.3 | 7,277 | 35.1 | 7605 | 45.3 | 9,918 | 55.5 | 12,421 | 13.05 | 62.1 |
| 60 | **20.1** | 5,047 | **93.4%** | **33.8** | 7,279 | **35.8** | 7622 | **46.3** | 9,952 | 55.8 | 12,206 | 12.07 | 62.1 |
| 61 | 20.5 | 5,055 | 93.4% | 34.5 | 7,296 | 36.7 | 7684 | 46.9 | 9,930 | 56.1 | 12,048 | 11.08 | 62.1 |
| 62 | 20.8 | 5,062 | 93.5% | 35.1 | 7,311 | 37.6 | 7743 | 47.6 | 9,909 | 56.3 | 11,887 | 10.10 | 62.1 |
| 63 | 21.2 | 5,068 | 93.5% | 35.8 | 7,326 | 38.5 | 7801 | 48.3 | 9,889 | 56.5 | 11,721 | 9.11 | 62.1 |
| 64 | 21.6 | 5,075 | 93.6% | 36.5 | 7,340 | 39.4 | 7856 | 49.0 | 9,868 | 56.7 | 11,552 | 8.13 | 62.1 |
| 65 | **21.9** | 5,081 | **93.6%** | **37.1** | 7,354 | **40.3** | 7910 | **49.7** | 9,849 | 56.8 | 11,379 | 7.14 | 62.1 |
| 66 | 22.4 | 5,119 | 93.5% | 37.6 | 7,341 | 41.0 | 7929 | 50.6 | 9,876 | 57.4 | 11,328 | 6.16 | 62.1 |
| 67 | 22.9 | 5,156 | 93.5% | 38.1 | 7,329 | 41.7 | 7947 | 51.4 | 9,902 | 58.1 | 11,275 | 6.00 | 62.1 |
| 68 | 23.4 | 5,191 | 93.4% | 38.6 | 7,317 | 42.4 | 7965 | 52.3 | 9,928 | 58.6 | 11,220 | 6.00 | 62.1 |
| 69 | 23.9 | 5,226 | 93.4% | 39.0 | 7,305 | 43.1 | 7982 | 53.2 | 9,954 | 59.2 | 11,161 | 6.00 | 62.1 |
| 70 | **24.4** | 5,259 | **93.3%** | **39.5** | 7,294 | **43.8** | 7999 | **54.1** | 9,979 | 59.8 | 11,100 | 6.00 | 62.1 |

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on turbine efficiency, gross head, and power output.
5. Turbine prototype efficiency at 1% below the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1997 Model Hill Curve cavitation limits with a 5' safety margin.
8. The tailwater is based on the CROHMS data between 1990-1997. The turbine operating limit is based on this minimum TW with a 5' SM.
9. The generator limit is based on generator nameplate of 69.0 MVA @ 0.9 pf = 62.1 MW and the turbine shaft limit is 62.1 MW.

Prepared by HDC, June 2000
RJW, DMW

**Table A - 8. One percent table for Bonneville Units 1 to 10 with no screens installed**

🟩 Maximum Power Output @ 1%

🟨 T = -0.9847GH + 71.148 Gross Head to Tailwater Based on CROHMS

# Bonneville, U1-10, 1% Table with No Screens Installed

## Based on the 1998 Index test (Scintillation) and the 1956 Prototype Hill Curve

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (ft) | (mW) |
| 35 | **7.7** | 3,294 | **86.5%** | **13.2** | 5,272 | **22.9** | 9030 | **31.0** | 12,355 | 35.9 | 14,820 | 36.68 | 62.1 |
| 36 | 7.7 | 3,224 | 86.8% | 13.7 | 5,296 | 23.4 | 8939 | 32.3 | 12,449 | 37.3 | 14,918 | 35.70 | 62.1 |
| 37 | 7.8 | 3,158 | 87.1% | 14.2 | 5,317 | 23.9 | 8852 | 33.5 | 12,536 | 38.6 | 15,010 | 34.71 | 62.1 |
| 38 | 7.8 | 3,095 | 87.5% | 14.7 | 5,336 | 24.5 | 8768 | 34.8 | 12,614 | 40.0 | 15,098 | 33.73 | 62.1 |
| 39 | 7.9 | 3,036 | 87.8% | 15.2 | 5,353 | 25.0 | 8688 | 36.0 | 12,686 | 41.4 | 15,180 | 32.74 | 62.1 |
| 40 | **7.9** | 2,980 | **88.2%** | **15.7** | 5,368 | **25.5** | 8610 | **37.3** | 12,751 | 42.8 | 15,258 | 31.76 | 62.1 |
| 41 | 8.1 | 2,969 | 88.3% | 16.3 | 5,414 | 26.8 | 8810 | 38.5 | 12,825 | 44.2 | 15,346 | 30.78 | 62.1 |
| 42 | 8.2 | 2,959 | 88.5% | 16.8 | 5,456 | 28.1 | 8999 | 39.8 | 12,895 | 45.6 | 15,429 | 29.79 | 62.1 |
| 43 | 8.4 | 2,949 | 88.7% | 17.4 | 5,496 | 29.4 | 9177 | 41.0 | 12,959 | 47.1 | 15,508 | 28.81 | 62.1 |
| 44 | 8.6 | 2,939 | 88.9% | 18.0 | 5,534 | 30.7 | 9346 | 42.3 | 13,019 | 48.5 | 15,583 | 27.82 | 62.1 |
| 45 | **8.8** | 2,930 | **89.1%** | **18.5** | 5,569 | **32.0** | 9506 | **43.5** | 13,075 | 49.9 | 15,654 | 26.84 | 62.1 |
| 46 | 9.0 | 2,939 | 89.3% | 19.2 | 5,626 | 33.2 | 9630 | 44.4 | 13,048 | 51.3 | 15,728 | 25.85 | 62.1 |
| 47 | 9.2 | 2,946 | 89.4% | 19.8 | 5,680 | 34.4 | 9749 | 45.4 | 13,021 | 52.7 | 15,799 | 24.87 | 62.1 |
| 48 | 9.4 | 2,954 | 89.6% | 20.4 | 5,732 | 35.6 | 9861 | 46.3 | 12,995 | 54.1 | 15,865 | 23.88 | 62.1 |
| 49 | 9.6 | 2,961 | 89.7% | 21.1 | 5,781 | 36.8 | 9968 | 47.3 | 12,969 | 55.5 | 15,928 | 22.90 | 62.1 |
| 50 | **9.8** | 2,968 | **89.9%** | **21.7** | 5,827 | **37.9** | 10070 | **48.2** | 12,944 | 56.9 | 15,988 | 21.91 | 62.1 |
| 51 | 10.1 | 2,978 | 90.0% | 22.5 | 5,919 | 38.5 | 9991 | 49.0 | 12,866 | 57.5 | 15,786 | 20.93 | 62.1 |
| 52 | 10.3 | 2,989 | 90.1% | 23.3 | 6,006 | 39.0 | 9914 | 49.8 | 12,811 | 58.0 | 15,579 | 19.94 | 62.1 |
| 53 | 10.5 | 2,999 | 90.2% | 24.2 | 6,090 | 39.5 | 9840 | 50.6 | 12,757 | 58.5 | 15,365 | 18.96 | 62.1 |
| 54 | 10.8 | 3,008 | 90.4% | 25.0 | 6,170 | 40.0 | 9768 | 51.4 | 12,705 | 58.9 | 15,145 | 17.97 | 62.1 |
| 55 | **11.0** | 3,017 | **90.5%** | **25.8** | 6,247 | **40.5** | 9699 | **51.9** | 12,578 | 59.3 | 14,919 | 16.99 | 62.1 |
| 56 | 11.3 | 3,039 | 90.4% | 26.3 | 6,258 | 41.8 | 9851 | 53.3 | 12,677 | 59.6 | 14,638 | 16.00 | 62.1 |
| 57 | 11.6 | 3,060 | 90.4% | 26.8 | 6,269 | 43.2 | 9997 | 54.6 | 12,774 | 59.8 | 14,352 | 15.02 | 62.1 |
| 58 | 11.9 | 3,080 | 90.3% | 27.3 | 6,280 | 44.5 | 10139 | 55.9 | 12,867 | 60.0 | 14,063 | 14.04 | 62.1 |
| 59 | 12.1 | 3,100 | 90.3% | 27.8 | 6,290 | 45.9 | 10276 | 57.2 | 12,958 | 60.1 | 13,771 | 13.05 | 62.1 |
| 60 | **12.4** | 3,118 | **90.2%** | **28.3** | 6,300 | **47.2** | 10410 | 58.6 | 13,046 | 60.1 | 13,476 | 12.07 | 62.1 |
| 61 | 12.7 | 3,145 | 90.1% | 28.7 | 6,293 | 48.4 | 10495 | 59.7 | 13,095 | 60.1 | 13,221 | 11.08 | 62.1 |
| 62 | 13.0 | 3,172 | 90.0% | 29.1 | 6,287 | 49.5 | 10578 | 60.9 | 13,142 | 60.0 | 12,961 | 10.10 | 62.1 |
| 63 | 13.4 | 3,197 | 89.9% | 29.5 | 6,281 | 50.7 | 10659 | 62.0 | 13,188 | 59.8 | 12,696 | 9.11 | 62.1 |
| 64 | 13.7 | 3,222 | 89.9% | 29.9 | 6,275 | 51.8 | 10738 | 63.1 | 13,233 | 59.5 | 12,425 | 8.13 | 62.1 |
| 65 | **14.0** | 3,246 | **89.8%** | **30.4** | 6,270 | **52.9** | 10815 | **64.3** | 13,278 | 59.2 | 12,148 | 7.14 | 62.1 |
| 66 | 14.4 | 3,287 | 89.7% | 31.0 | 6,322 | 52.8 | 10640 | 65.1 | 13,272 | 59.7 | 12,076 | 6.16 | 62.1 |
| 67 | 14.8 | 3,327 | 89.5% | 31.7 | 6,372 | 52.7 | 10470 | 66.0 | 13,266 | 60.1 | 12,000 | 6.00 | 62.1 |
| 68 | 15.2 | 3,366 | 89.4% | 32.4 | 6,422 | 52.6 | 10305 | 66.9 | 13,261 | 60.5 | 11,921 | 6.00 | 62.1 |
| 69 | 15.6 | 3,403 | 89.3% | 33.1 | 6,471 | 52.4 | 10145 | 67.8 | 13,257 | 60.9 | 11,838 | 6.00 | 62.1 |
| 70 | **16.0** | 3,440 | **89.2%** | **33.8** | 6,519 | **52.3** | 9990 | **68.6** | 13,253 | 61.3 | 11,751 | 6.00 | 62.1 |

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on model efficiency, gross head, and power output.
5. Turbine model efficiency at a 1% drop from the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1955 Model Hill Curve cavitation limits with a 1' safety margin.
8. The tailwater is based on the CROHMS data between 1990-1997. The turbine operating limit is based on this min TW with a 1' SM.
9. The generator limit is based on 115% of generator nameplate.

Prepared by HDC, July 2001
RJW, DMW

## With Fish Screens

### Table A - 9. One percent table for Bonneville Units 1 to 10 with screens installed – new MGRs

🟩 Maximum Power Output @ 1% 🟨 T = -0.9847GH + 71.148 Gross Head to Tailwater Based on CROHMS

# Bonneville, U1-10, New MG Runners, 1% Table with Screens Installed

## Based on the 1999 U6 Index Test and the 1997 Model Hill Curve

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (%) | (ft) | (mW) |
| 35 | **13.2** | 5,678 | **89.7%** | **17.6** | 6,757 | **19.2** | 7,303 | **24.0** | 9,200 | 31.8 | 12,991 | 36.68 | 62.1 |
| 36 | 13.4 | 5,615 | 89.8% | 18.2 | 6,771 | 19.9 | 7,321 | 24.6 | 9,181 | 33.0 | 13,043 | 35.70 | 62.1 |
| 37 | 13.6 | 5,555 | 89.9% | 18.7 | 6,783 | 20.5 | 7,337 | 25.3 | 9,163 | 34.1 | 13,089 | 34.71 | 62.1 |
| 38 | 13.9 | 5,499 | 90.1% | 19.3 | 6,794 | 21.1 | 7,352 | 26.0 | 9,145 | 35.3 | 13,131 | 33.73 | 62.1 |
| 39 | 14.1 | 5,445 | 90.2% | 19.8 | 6,804 | 21.7 | 7,366 | 26.6 | 9,128 | 36.4 | 13,168 | 32.74 | 62.1 |
| 40 | **14.3** | 5,394 | **91.1%** | **20.4** | 6,753 | **22.4** | 7,314 | **27.3** | 9,031 | 37.6 | 13,200 | 31.76 | 62.1 |
| 41 | 14.6 | 5,355 | 91.2% | 21.0 | 6,754 | 23.3 | 7,423 | 28.4 | 9,148 | 38.8 | 13,245 | 30.78 | 62.1 |
| 42 | 14.8 | 5,318 | 91.3% | 21.5 | 6,755 | 24.2 | 7,526 | 29.5 | 9,259 | 40.0 | 13,285 | 29.79 | 62.1 |
| 43 | 15.1 | 5,282 | 91.5% | 22.0 | 6,756 | 25.1 | 7,624 | 30.5 | 9,363 | 41.1 | 13,322 | 28.81 | 62.1 |
| 44 | 15.3 | 5,248 | 91.6% | 22.6 | 6,756 | 26.1 | 7,716 | 31.6 | 9,463 | 42.3 | 13,355 | 27.82 | 62.1 |
| 45 | **15.6** | 5,216 | **91.7%** | **23.1** | 6,756 | **27.0** | 7,804 | **32.7** | 9,557 | 43.5 | 13,384 | 26.84 | 62.1 |
| 46 | 15.8 | 5,164 | 91.8% | 23.7 | 6,763 | 27.4 | 7,741 | 33.6 | 9,603 | 44.6 | 13,379 | 25.85 | 62.1 |
| 47 | 16.0 | 5,114 | 91.9% | 24.3 | 6,769 | 27.8 | 7,681 | 34.6 | 9,648 | 45.7 | 13,371 | 24.87 | 62.1 |
| 48 | 16.1 | 5,067 | 92.1% | 24.8 | 6,775 | 28.2 | 7,624 | 35.5 | 9,689 | 46.7 | 13,358 | 23.88 | 62.1 |
| 49 | 16.3 | 5,022 | 92.2% | 25.4 | 6,780 | 28.7 | 7,568 | 36.5 | 9,729 | 47.8 | 13,342 | 22.90 | 62.1 |
| 50 | **16.5** | 4,978 | **92.3%** | **26.0** | 6,785 | **29.1** | 7,514 | **37.4** | 9,766 | 48.8 | 13,323 | 21.91 | 62.1 |
| 51 | 16.9 | 4,981 | 92.4% | 26.5 | 6,792 | 29.6 | 7,496 | 38.3 | 9,809 | 49.9 | 13,326 | 20.93 | 62.1 |
| 52 | 17.2 | 4,983 | 92.5% | 27.1 | 6,798 | 30.1 | 7,479 | 39.3 | 9,850 | 51.0 | 13,326 | 19.94 | 62.1 |
| 53 | 17.5 | 4,985 | 92.5% | 27.7 | 6,804 | 30.7 | 7,462 | 40.2 | 9,889 | 52.1 | 13,323 | 18.96 | 62.1 |
| 54 | 17.9 | 4,988 | 92.6% | 28.3 | 6,810 | 31.2 | 7,445 | 41.2 | 9,927 | 53.1 | 13,317 | 17.97 | 62.1 |
| 55 | **18.2** | 4,990 | **92.7%** | **28.8** | 6,815 | **31.8** | 7,429 | **42.1** | 9,962 | 54.2 | 13,307 | 16.99 | 62.1 |
| 56 | 18.6 | 5,002 | 92.7% | 29.4 | 6,817 | 32.5 | 7,464 | 43.1 | 10,003 | 54.6 | 13,116 | 16.00 | 62.1 |
| 57 | 19.0 | 5,014 | 92.7% | 29.9 | 6,820 | 33.2 | 7,498 | 44.0 | 10,042 | 54.9 | 12,921 | 15.02 | 62.1 |
| 58 | 19.3 | 5,026 | 92.8% | 30.4 | 6,823 | 34.0 | 7,530 | 45.0 | 10,079 | 55.3 | 12,722 | 14.04 | 62.1 |
| 59 | 19.7 | 5,037 | 92.8% | 31.0 | 6,825 | 34.7 | 7,562 | 45.9 | 10,115 | 55.5 | 12,519 | 13.05 | 62.1 |
| 60 | **20.1** | 5,047 | **92.8%** | **31.5** | 6,827 | **35.4** | 7,592 | **46.9** | 10,150 | 55.8 | 12,313 | 12.07 | 62.1 |
| 61 | 20.5 | 5,055 | 92.8% | 32.1 | 6,842 | 36.6 | 7,702 | 47.6 | 10,128 | 56.1 | 12,157 | 11.08 | 62.1 |
| 62 | 20.8 | 5,062 | 92.9% | 32.8 | 6,857 | 37.7 | 7,808 | 48.3 | 10,106 | 56.3 | 11,996 | 10.10 | 62.1 |
| 63 | 21.2 | 5,068 | 92.9% | 33.4 | 6,871 | 38.8 | 7,911 | 49.0 | 10,085 | 56.5 | 11,832 | 9.11 | 62.1 |
| 64 | 21.6 | 5,075 | 93.0% | 34.0 | 6,884 | 40.0 | 8,010 | 49.7 | 10,064 | 56.7 | 11,663 | 8.13 | 62.1 |
| 65 | **21.9** | 5,081 | **93.0%** | **34.6** | 6,897 | **41.1** | 8,106 | **50.4** | 10,044 | 56.8 | 11,490 | 7.14 | 62.1 |
| 66 | 22.4 | 5,119 | 92.9% | 35.0 | 6,885 | 41.9 | 8,153 | 51.2 | 10,072 | 57.4 | 11,440 | 6.16 | 62.1 |
| 67 | 22.9 | 5,156 | 92.9% | 35.5 | 6,873 | 42.8 | 8,198 | 52.1 | 10,099 | 58.1 | 11,386 | 6.00 | 62.1 |
| 68 | 23.4 | 5,191 | 92.8% | 35.9 | 6,862 | 43.6 | 8,242 | 53.0 | 10,126 | 58.6 | 11,330 | 6.00 | 62.1 |
| 69 | 23.9 | 5,226 | 92.8% | 36.4 | 6,851 | 44.5 | 8,286 | 53.9 | 10,152 | 59.2 | 11,271 | 6.00 | 62.1 |
| 70 | **24.4** | 5,259 | **92.7%** | **36.8** | 6,841 | **45.3** | 8,328 | **54.8** | 10,177 | 59.8 | 11,209 | 6.00 | 62.1 |

Prepared by HDC, June 2000
RJW, DMW

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on turbine efficiency, gross head, and power output.
5. Turbine prototype efficiency at 1% below the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1997 Model Hill Curve cavitation limits with a 5' safety margin.
8. The tailwater is based on the CROHMS data between 1990-1997. The turbine operating limit is based on this minimum TW with a 5' SM.
9. The generator limit is based on generator nameplate of 69.0 MVA @ 0.9 pf = 62.1 MW and the turbine shaft limit is 62.1 MW.

## Table A - 10. One percent table for Bonneville Units 1 to 10 with STS installed

# Bonneville I U1-10 STS

## Based on the 1998 Index test (Scintillation) and the 1956 Prototype Hill Curve w/STS Adjustment Factor

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (ft) | (mW) |
| 35 | **8.2** | 3,529 | **84.5%** | **12.7** | 5,192 | **20.2** | 8,131 | **29.2** | 11,894 | 35.9 | 15,315 | 36.68 | 62.1 |
| 36 | 8.3 | 3,454 | 84.7% | 13.3 | 5,251 | 21.3 | 8,320 | 30.3 | 11,999 | 37.3 | 15,396 | 35.70 | 62.1 |
| 37 | 8.3 | 3,384 | 84.9% | 13.8 | 5,307 | 22.4 | 8,498 | 31.5 | 12,096 | 38.6 | 15,471 | 34.71 | 62.1 |
| 38 | 8.4 | 3,316 | 85.1% | 14.4 | 5,358 | 23.5 | 8,664 | 32.7 | 12,186 | 40.0 | 15,541 | 33.73 | 62.1 |
| 39 | 8.4 | 3,253 | 85.3% | 14.9 | 5,406 | 24.6 | 8,820 | 33.8 | 12,269 | 41.4 | 15,606 | 32.74 | 62.1 |
| 40 | **8.5** | 3,192 | **86.2%** | **15.1** | 5,284 | **22.6** | 7,818 | **35.1** | 12,270 | 42.8 | 15,666 | 31.76 | 62.1 |
| 41 | 8.7 | 3,181 | 86.3% | 15.6 | 5,329 | 23.7 | 7,983 | 36.2 | 12,341 | 44.2 | 15,747 | 30.78 | 62.1 |
| 42 | 8.8 | 3,170 | 86.5% | 16.2 | 5,371 | 24.8 | 8,140 | 37.4 | 12,407 | 45.6 | 15,824 | 29.79 | 62.1 |
| 43 | 9.0 | 3,159 | 86.7% | 16.7 | 5,410 | 25.9 | 8,287 | 38.6 | 12,469 | 47.1 | 15,897 | 28.81 | 62.1 |
| 44 | 9.2 | 3,149 | 86.9% | 17.3 | 5,447 | 27.0 | 8,426 | 39.7 | 12,526 | 48.5 | 15,965 | 27.82 | 62.1 |
| 45 | **9.4** | 3,140 | **87.1%** | **17.8** | 5,481 | **28.2** | 8,558 | **40.9** | 12,579 | 49.9 | 16,029 | 26.84 | 62.1 |
| 46 | 9.6 | 3,148 | 87.3% | 18.4 | 5,537 | 29.2 | 8,665 | 41.8 | 12,553 | 51.3 | 16,101 | 25.85 | 62.1 |
| 47 | 9.8 | 3,157 | 87.4% | 19.1 | 5,590 | 30.2 | 8,767 | 42.7 | 12,527 | 52.7 | 16,169 | 24.87 | 62.1 |
| 48 | 10.1 | 3,165 | 87.6% | 19.7 | 5,641 | 31.3 | 8,864 | 43.6 | 12,501 | 54.1 | 16,233 | 23.88 | 62.1 |
| 49 | 10.3 | 3,172 | 87.7% | 20.3 | 5,688 | 32.3 | 8,956 | 44.5 | 12,476 | 55.5 | 16,293 | 22.90 | 62.1 |
| 50 | **10.6** | 3,180 | **87.9%** | **20.9** | 5,734 | **33.3** | 9,044 | **45.4** | 12,451 | 56.9 | 16,350 | 21.91 | 62.1 |
| 51 | 10.8 | 3,191 | 88.0% | 21.7 | 5,824 | 33.9 | 8,997 | 46.1 | 12,375 | 57.5 | 16,154 | 20.93 | 62.1 |
| 52 | 11.1 | 3,202 | 88.1% | 22.5 | 5,910 | 34.4 | 8,952 | 46.8 | 12,302 | 58.0 | 15,952 | 19.94 | 62.1 |
| 53 | 11.3 | 3,213 | 88.2% | 23.2 | 5,992 | 34.9 | 8,908 | 47.4 | 12,232 | 58.5 | 15,743 | 18.96 | 62.1 |
| 54 | 11.5 | 3,223 | 88.4% | 24.0 | 6,071 | 35.5 | 8,866 | 48.1 | 12,163 | 58.9 | 15,528 | 17.97 | 62.1 |
| 55 | **11.8** | 3,233 | **88.5%** | **24.8** | 6,146 | **36.0** | 8,824 | **48.8** | 12,097 | 59.3 | 15,306 | 16.99 | 62.1 |
| 56 | 12.1 | 3,256 | 88.4% | 25.3 | 6,157 | 37.2 | 8,946 | 50.1 | 12,193 | 59.6 | 15,018 | 16.00 | 62.1 |
| 57 | 12.4 | 3,278 | 88.4% | 25.8 | 6,168 | 38.3 | 9,063 | 51.3 | 12,286 | 59.8 | 14,727 | 15.02 | 62.1 |
| 58 | 12.7 | 3,300 | 88.3% | 26.3 | 6,179 | 39.4 | 9,177 | 52.6 | 12,376 | 60.0 | 14,278 | 14.04 | 62.1 |
| 59 | 13.0 | 3,321 | 88.3% | 26.7 | 6,189 | 40.6 | 9,287 | 53.8 | 12,463 | 60.1 | 13,983 | 13.05 | 62.1 |
| 60 | **13.3** | 3,341 | **88.2%** | **27.2** | 6,199 | **41.7** | 9,394 | **55.1** | 12,548 | 60.1 | 13,830 | 12.07 | 62.1 |
| 61 | 13.6 | 3,370 | 88.1% | 27.6 | 6,192 | 42.7 | 9,460 | 56.2 | 12,595 | 60.1 | 13,575 | 11.08 | 62.1 |
| 62 | 14.0 | 3,398 | 88.0% | 28.0 | 6,186 | 43.6 | 9,525 | 57.2 | 12,641 | 60.0 | 13,314 | 10.10 | 62.1 |
| 63 | 14.3 | 3,426 | 87.9% | 28.4 | 6,180 | 44.6 | 9,588 | 58.3 | 12,685 | 59.8 | 13,047 | 9.11 | 62.1 |
| 64 | 14.7 | 3,452 | 87.9% | 28.8 | 6,175 | 45.5 | 9,649 | 59.4 | 12,729 | 59.5 | 12,774 | 8.13 | 62.1 |
| 65 | **15.0** | 3,477 | **87.8%** | **29.2** | 6,170 | **46.5** | 9,709 | **60.5** | 12,772 | 59.2 | 12,495 | 7.14 | 62.1 |
| 66 | 15.4 | 3,522 | 87.7% | 29.9 | 6,221 | 46.5 | 9,582 | 61.3 | 12,767 | 59.7 | 12,418 | 6.16 | 62.1 |
| 67 | 15.8 | 3,564 | 87.5% | 30.5 | 6,271 | 46.5 | 9,458 | 62.1 | 12,762 | 60.1 | 12,337 | 6.00 | 62.1 |
| 68 | 16.3 | 3,606 | 87.4% | 31.2 | 6,320 | 46.6 | 9,339 | 62.9 | 12,757 | 60.5 | 12,253 | 6.00 | 62.1 |
| 69 | 16.7 | 3,646 | 87.3% | 31.8 | 6,368 | 46.6 | 9,222 | 63.7 | 12,754 | 60.9 | 12,165 | 6.00 | 62.1 |
| 70 | **17.1** | 3,686 | **87.2%** | **32.5** | 6,415 | **46.6** | 9,110 | **64.5** | 12,750 | 61.3 | 12,073 | 6.00 | 62.1 |

Prepared by HDC, July 2001
RJW, DMW

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on model efficiency, gross head, and power output.
5. Turbine model efficiency at a 1% drop from the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1955 Model Hill Curve cavitation limits with a 1' safety margin.
8. The tailwater is based on the CROHMS data between 1990-1997. The turbine operating limit is based on this min TW with a 1' SM.
9. The generator limit is based on 115% of generator nameplate.

## A.4.4.2 Bonneville II Units

### Without Screens

**Table A - 11. One percent table for Bonneville Units 11 to 18 with no screens installed**

🟩 Maximum Power Output @ 1% 🟨 TW = -0.9847GH + 71.148 Gross Head to Tailwater Based on CROHMS

# Bonneville 2, Units 11-18, 1% Table with No Screens Installed

## Based on the 1979 Model Test and 1995 Unit 16 NS Index Test

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (ft) | (mW) |
| 30 | **20.9** | 10,493 | **84.9%** | **22.4** | 10,583 | **27.0** | 12642 | **36.0** | 17,019 | 34.7 | 16,381 | 41.61 | 76.5 |
| 31 | 21.3 | 10,378 | 85.4% | 23.1 | 10,532 | 27.4 | 12336 | 36.7 | 16,737 | 36.9 | 16,874 | 40.62 | 76.5 |
| 32 | 21.8 | 10,270 | 85.8% | 23.9 | 10,481 | 27.8 | 12048 | 37.5 | 16,470 | 39.3 | 17,370 | 39.64 | 76.5 |
| 33 | 22.3 | 10,169 | 86.3% | 24.6 | 10,430 | 28.1 | 11777 | 38.3 | 16,217 | 41.7 | 17,869 | 38.65 | 76.5 |
| 34 | 22.7 | 10,073 | 86.8% | 25.4 | 10,380 | 28.5 | 11521 | 39.1 | 15,975 | 44.1 | 18,371 | 37.67 | 76.5 |
| 35 | **23.2** | 9,983 | **87.2%** | **26.2** | 10,330 | **28.9** | 11278 | **39.9** | 15,746 | 46.7 | 18,875 | 36.68 | 76.5 |
| 36 | 23.8 | 9,951 | 87.5% | 27.0 | 10,341 | 29.9 | 11316 | 41.2 | 15,773 | 49.0 | 19,272 | 35.70 | 76.5 |
| 37 | 24.4 | 9,920 | 87.9% | 27.9 | 10,350 | 30.9 | 11349 | 42.6 | 15,795 | 51.4 | 19,669 | 34.71 | 76.5 |
| 38 | 24.9 | 9,891 | 88.2% | 28.8 | 10,356 | 32.0 | 11378 | 43.9 | 15,813 | 53.9 | 20,066 | 33.73 | 76.5 |
| 39 | 25.5 | 9,863 | 88.5% | 29.7 | 10,360 | 33.0 | 11403 | 45.3 | 15,827 | 56.4 | 20,462 | 32.74 | 76.5 |
| 40 | **26.1** | 9,837 | **88.8%** | **30.5** | 10,362 | **34.0** | 11425 | **46.7** | 15,837 | 59.0 | 20,859 | 31.76 | 76.5 |
| 41 | 26.7 | 9,817 | 89.0% | 31.3 | 10,336 | 34.9 | 11399 | 48.0 | 15,869 | 61.2 | 21,063 | 30.78 | 76.5 |
| 42 | 27.3 | 9,798 | 89.2% | 32.1 | 10,310 | 35.8 | 11374 | 49.4 | 15,897 | 63.4 | 21,264 | 29.79 | 76.5 |
| 43 | 27.9 | 9,780 | 89.4% | 32.8 | 10,285 | 36.6 | 11348 | 50.8 | 15,922 | 65.6 | 21,460 | 28.81 | 76.5 |
| 44 | 28.5 | 9,763 | 89.7% | 33.6 | 10,259 | 37.5 | 11323 | 52.2 | 15,943 | 67.8 | 21,652 | 27.82 | 76.5 |
| 45 | **29.1** | 9,747 | **89.9%** | **34.3** | 10,234 | **38.3** | 11298 | **53.5** | 15,962 | 70.1 | 21,840 | 26.84 | 76.5 |
| 46 | 29.7 | 9,726 | 90.0% | 35.1 | 10,230 | 39.2 | 11300 | 55.0 | 16,021 | 72.1 | 21,913 | 25.85 | 76.5 |
| 47 | 30.3 | 9,707 | 90.0% | 35.9 | 10,226 | 40.1 | 11301 | 55.8 | 15,888 | 74.2 | 21,981 | 24.87 | 76.5 |
| 48 | 30.9 | 9,688 | 90.1% | 36.7 | 10,222 | 41.0 | 11302 | 56.6 | 15,761 | 76.3 | 22,044 | 23.88 | 76.5 |
| 49 | 31.4 | 9,671 | 90.2% | 37.5 | 10,217 | 41.9 | 11303 | 57.3 | 15,637 | 76.7 | 21,623 | 22.90 | 76.5 |
| 50 | **32.0** | 9,653 | **90.3%** | **38.3** | 10,212 | **42.8** | 11303 | **60.8** | 16,226 | 76.7 | 21,111 | 21.91 | 76.5 |
| 51 | 32.5 | 9,608 | 90.4% | 39.2 | 10,245 | 44.0 | 11373 | 62.9 | 16,446 | 76.7 | 20,584 | 20.93 | 76.5 |
| 52 | 33.0 | 9,565 | 90.4% | 40.1 | 10,276 | 45.1 | 11439 | 65.0 | 16,657 | 76.7 | 20,079 | 19.94 | 76.5 |
| 53 | 33.5 | 9,523 | 90.5% | 41.0 | 10,305 | 46.3 | 11503 | 67.1 | 16,860 | 76.7 | 19,594 | 18.96 | 76.5 |
| 54 | 34.0 | 9,482 | 90.6% | 41.9 | 10,333 | 47.4 | 11563 | 69.2 | 17,054 | 76.7 | 19,128 | 17.97 | 76.5 |
| 55 | **34.5** | 9,444 | **90.6%** | **42.8** | 10,360 | **48.6** | 11622 | **71.3** | 17,240 | 76.7 | 18,680 | 16.99 | 76.5 |
| 56 | 35.0 | 9,406 | 90.8% | 44.2 | 10,476 | 49.5 | 11611 | 71.6 | 16,977 | 76.7 | 18,289 | 16.00 | 76.5 |
| 57 | 35.4 | 9,370 | 91.1% | 45.6 | 10,586 | 50.5 | 11599 | 72.0 | 16,723 | 76.7 | 17,913 | 15.02 | 76.5 |
| 58 | 35.9 | 9,335 | 91.3% | 46.9 | 10,691 | 51.4 | 11587 | 72.4 | 16,478 | 76.7 | 17,550 | 14.04 | 76.5 |
| 59 | 36.4 | 9,301 | 91.5% | 48.3 | 10,792 | 52.4 | 11574 | 72.7 | 16,240 | 76.7 | 17,199 | 13.05 | 76.5 |
| 60 | **36.9** | 9,269 | **91.7%** | **49.7** | 10,887 | **53.3** | 11562 | **73.1** | 16,010 | 76.7 | 16,861 | 12.07 | 76.5 |
| 61 | 37.6 | 9,296 | 91.6% | 50.1 | 10,800 | 53.6 | 11446 | 76.3 | 16,458 | 76.7 | 16,570 | 11.08 | 76.5 |
| 62 | 38.4 | 9,322 | 91.6% | 50.5 | 10,715 | 53.9 | 11334 | 79.5 | 16,892 | 76.7 | 16,288 | 10.10 | 76.5 |
| 63 | 39.1 | 9,347 | 91.5% | 50.8 | 10,634 | 54.2 | 11226 | 82.8 | 17,313 | 76.7 | 16,016 | 9.11 | 76.5 |
| 64 | 39.8 | 9,371 | 91.4% | 51.2 | 10,555 | 54.5 | 11121 | 86.0 | 17,723 | 76.7 | 15,752 | 8.13 | 76.5 |
| 65 | **40.5** | 9,395 | **91.3%** | **51.6** | 10,479 | **54.8** | 11020 | **89.2** | 18,121 | 76.7 | 15,496 | 7.14 | 76.5 |
| 66 | 41.2 | 9,399 | 91.3% | 52.6 | 10,519 | 55.7 | 11016 | 90.6 | 18,127 | 76.7 | 15,258 | 6.16 | 76.5 |
| 67 | 41.8 | 9,403 | 91.3% | 53.6 | 10,558 | 56.5 | 11013 | 92.0 | 18,133 | 76.7 | 15,027 | 6.00 | 76.5 |
| 68 | 42.4 | 9,407 | 91.3% | 54.6 | 10,595 | 57.3 | 11010 | 93.4 | 18,139 | 76.7 | 14,803 | 6.00 | 76.5 |
| 69 | 43.1 | 9,410 | 91.3% | 55.6 | 10,632 | 58.2 | 11007 | 94.8 | 18,145 | 76.7 | 14,585 | 6.00 | 76.5 |
| 70 | **43.7** | 9,414 | **91.3%** | **56.6** | 10,668 | **59.0** | 11004 | **96.2** | 18,150 | 76.7 | 14,373 | 6.00 | 76.5 |

Prepared by HDC, January 2001
RJW, DMW

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on turbine efficiency, gross head, and power output.
5. Turbine prototype efficiency at 1% below the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1979 Model Test cavitation limits with a 10 foot safety margin.
8. The tailwater is based on the CROHMS data between 1993-1998. The turbine operating limit is based on this minimum TW with a 10 foot SM.
9. The generator limit is based on 115% of generator nameplate. Nameplate is 70.00 MVA @ 0.95 pf = 76.50 MW.

## With Fish Screens

**Table A - 12. One percent table for Bonneville Units 11 to 18 with STS installed**

🟩 Maximum Power Output @ 1%

🟨 T = -0.9847GH + 71.148 Gross Head to Tailwater Based on CROHMS

# Bonneville 2, Units 11-18, 1% Table with STS Installed

Based on the 1979 Model Test and 1995 Unit 16 STS Index Test with STS adjustment Factor

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (ft) | (mW) |
| 30 | **20.9** | 10,493 | **84.4%** | **22.9** | 10,881 | **26.7** | 12545 | **36.5** | 17,395 | 34.7 | 16,439 | 41.61 | 76.5 |
| 31 | 21.3 | 10,378 | 84.9% | 23.6 | 10,828 | 27.2 | 12303 | 37.6 | 17,230 | 36.9 | 16,918 | 40.62 | 76.5 |
| 32 | 21.8 | 10,270 | 85.3% | 24.4 | 10,775 | 27.7 | 12074 | 38.7 | 17,072 | 39.3 | 17,399 | 39.64 | 76.5 |
| 33 | 22.3 | 10,169 | 85.8% | 25.2 | 10,723 | 28.2 | 11857 | 39.7 | 16,919 | 41.7 | 17,882 | 38.65 | 76.5 |
| 34 | 22.7 | 10,073 | 86.3% | 26.0 | 10,670 | 28.7 | 11652 | 40.8 | 16,771 | 44.1 | 18,367 | 37.67 | 76.5 |
| 35 | **23.2** | 9,983 | **86.7%** | **26.7** | 10,619 | **29.2** | 11457 | **41.9** | 16,628 | 46.7 | 18,853 | 36.68 | 76.5 |
| 36 | 23.8 | 9,951 | 87.0% | 27.6 | 10,630 | 30.2 | 11492 | 43.3 | 16,657 | 49.0 | 19,275 | 35.70 | 76.5 |
| 37 | 24.4 | 9,920 | 87.4% | 28.5 | 10,639 | 31.2 | 11522 | 44.7 | 16,680 | 51.4 | 19,697 | 34.71 | 76.5 |
| 38 | 24.9 | 9,891 | 87.7% | 29.4 | 10,645 | 32.3 | 11549 | 46.1 | 16,699 | 53.9 | 20,120 | 33.73 | 76.5 |
| 39 | 25.5 | 9,863 | 88.0% | 30.3 | 10,649 | 33.3 | 11572 | 47.6 | 16,713 | 56.4 | 20,544 | 32.74 | 76.5 |
| 40 | **26.1** | 9,837 | **88.3%** | **31.2** | 10,651 | **34.3** | 11591 | **49.0** | 16,724 | 59.0 | 20,969 | 31.76 | 76.5 |
| 41 | 26.7 | 9,817 | 88.5% | 32.0 | 10,624 | 35.2 | 11564 | 50.4 | 16,756 | 61.2 | 21,200 | 30.78 | 76.5 |
| 42 | 27.3 | 9,798 | 88.7% | 32.8 | 10,597 | 36.1 | 11537 | 51.9 | 16,786 | 63.4 | 21,426 | 29.79 | 76.5 |
| 43 | 27.9 | 9,780 | 88.9% | 33.5 | 10,571 | 36.9 | 11511 | 53.3 | 16,812 | 65.6 | 21,649 | 28.81 | 76.5 |
| 44 | 28.5 | 9,763 | 89.2% | 34.3 | 10,544 | 37.8 | 11484 | 54.8 | 16,834 | 67.8 | 21,868 | 27.82 | 76.5 |
| 45 | **29.1** | 9,747 | **89.4%** | **35.1** | 10,518 | **38.6** | 11457 | **56.2** | 16,854 | 70.1 | 22,084 | 26.84 | 76.5 |
| 46 | 29.7 | 9,726 | 89.5% | 35.9 | 10,514 | 39.5 | 11458 | 57.7 | 16,917 | 72.1 | 22,092 | 25.85 | 76.5 |
| 47 | 30.3 | 9,707 | 89.5% | 36.7 | 10,510 | 40.4 | 11459 | 58.5 | 16,770 | 74.2 | 22,096 | 24.87 | 76.5 |
| 48 | 30.9 | 9,688 | 89.6% | 37.5 | 10,505 | 41.3 | 11458 | 59.3 | 16,629 | 76.3 | 22,095 | 23.88 | 76.5 |
| 49 | 31.4 | 9,671 | 89.7% | 38.3 | 10,500 | 42.2 | 11458 | 60.1 | 16,493 | 76.7 | 21,610 | 22.90 | 76.5 |
| 50 | **32.0** | 9,653 | **89.8%** | **39.1** | 10,495 | **43.2** | 11457 | **63.8** | 17,133 | 76.7 | 21,039 | 21.91 | 76.5 |
| 51 | 32.5 | 9,608 | 89.9% | 40.0 | 10,529 | 44.3 | 11522 | 66.0 | 17,365 | 76.7 | 20,528 | 20.93 | 76.5 |
| 52 | 33.0 | 9,565 | 89.9% | 41.0 | 10,561 | 45.4 | 11584 | 68.2 | 17,588 | 76.7 | 20,038 | 19.94 | 76.5 |
| 53 | 33.5 | 9,523 | 90.0% | 41.9 | 10,591 | 46.6 | 11644 | 70.4 | 17,801 | 76.7 | 19,567 | 18.96 | 76.5 |
| 54 | 34.0 | 9,482 | 90.1% | 42.8 | 10,620 | 47.7 | 11701 | 72.6 | 18,006 | 76.7 | 19,115 | 17.97 | 76.5 |
| 55 | **34.5** | 9,444 | **90.1%** | **43.8** | 10,647 | **48.9** | 11755 | **74.8** | 18,203 | 76.7 | 18,680 | 16.99 | 76.5 |
| 56 | 35.0 | 9,406 | 90.3% | 45.2 | 10,766 | 49.9 | 11763 | 75.2 | 17,925 | 76.7 | 18,297 | 16.00 | 76.5 |
| 57 | 35.4 | 9,370 | 90.6% | 46.6 | 10,880 | 50.9 | 11770 | 75.6 | 17,656 | 76.7 | 17,929 | 15.02 | 76.5 |
| 58 | 35.9 | 9,335 | 90.8% | 48.0 | 10,987 | 52.0 | 11776 | 76.0 | 17,397 | 76.7 | 17,573 | 14.04 | 76.5 |
| 59 | 36.4 | 9,301 | 91.0% | 49.4 | 11,090 | 53.0 | 11780 | 76.4 | 17,146 | 76.7 | 17,229 | 13.05 | 76.5 |
| 60 | **36.9** | 9,269 | **91.2%** | **50.8** | 11,188 | **54.1** | 11783 | **76.7** | 16,903 | 76.7 | 16,898 | 12.07 | 76.5 |
| 61 | 37.6 | 9,296 | 91.1% | 51.2 | 11,099 | 54.4 | 11666 | 80.1 | 17,375 | 76.7 | 16,615 | 11.08 | 76.5 |
| 62 | 38.4 | 9,322 | 91.1% | 51.6 | 11,012 | 54.7 | 11552 | 83.5 | 17,834 | 76.7 | 16,342 | 10.10 | 76.5 |
| 63 | 39.1 | 9,347 | 91.0% | 52.0 | 10,928 | 55.0 | 11442 | 86.9 | 18,279 | 76.7 | 16,077 | 9.11 | 76.5 |
| 64 | 39.8 | 9,371 | 90.9% | 52.3 | 10,847 | 55.3 | 11335 | 90.3 | 18,711 | 76.7 | 15,821 | 8.13 | 76.5 |
| 65 | **40.5** | 9,395 | **90.8%** | **52.7** | 10,769 | **55.6** | 11232 | **93.7** | 19,132 | 76.7 | 15,572 | 7.14 | 76.5 |
| 66 | 41.2 | 9,399 | 90.8% | 53.7 | 10,810 | 56.5 | 11235 | 95.1 | 19,138 | 76.7 | 15,331 | 6.16 | 76.5 |
| 67 | 41.8 | 9,403 | 90.8% | 54.8 | 10,850 | 57.3 | 11238 | 96.6 | 19,145 | 76.7 | 15,098 | 6.00 | 76.5 |
| 68 | 42.4 | 9,407 | 90.8% | 55.8 | 10,889 | 58.2 | 11240 | 98.1 | 19,151 | 76.7 | 14,871 | 6.00 | 76.5 |
| 69 | 43.1 | 9,410 | 90.8% | 56.8 | 10,926 | 59.1 | 11243 | 99.6 | 19,157 | 76.7 | 14,650 | 6.00 | 76.5 |
| 70 | **43.7** | 9,414 | **90.8%** | **57.8** | 10,963 | **59.9** | 11245 | **101.0** | 19,163 | 76.7 | 14,436 | 6.00 | 76.5 |

Prepared by HDC, January 2001
RJW, DMW

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on turbine efficiency, gross head, and power output.
5. Turbine prototype efficiency at 1% below the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1979 Model Test cavitation limits with a 10 foot safety margin.
8. The tailwater is based on the CROHMS data between 1993-1998. The turbine operating limit is based on this minimum TW with a 10 foot SM.
9. The generator limit is based on 115% of generator nameplate. Nameplate is 70.00 MVA @ 0.95 pf = 76.50 MW.

### A.4.4.3 The Dalles Units 1 to 14 (No Screens Installed at this Project)

**Table A - 13. One percent table for The Dalles Units 1 to 14 with no screens installed**

🟩 Maximum Power Output @ 1%

🟨 TW = -1.0277GH + 158.923 Gross Head to Tailwater Based on CROHMS

## The Dalles, Units 1-14, 1% Table with No Screens Installed

Based on the Unit 9 2000 Index Test and 1954 Model Hill Curve

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (%) | (ft) | (mW) |
| 55 | **24.8** | 6,796 | **87.0%** | **35.1** | 8,854 | **39.0** | 9719 | **44.1** | 11,108 | 61.3 | 16,600 | 102.40 | 89.7 |
| 56 | 24.9 | 6,706 | 87.2% | 35.9 | 8,875 | 40.1 | 9779 | 45.1 | 11,147 | 62.8 | 16,639 | 101.37 | 89.7 |
| 57 | 25.0 | 6,620 | 87.4% | 36.7 | 8,894 | 41.1 | 9837 | 46.2 | 11,184 | 64.2 | 16,675 | 100.34 | 89.7 |
| 58 | 25.2 | 6,537 | 87.5% | 37.5 | 8,912 | 42.1 | 9891 | 47.2 | 11,219 | 65.7 | 16,709 | 99.32 | 89.7 |
| 59 | 25.3 | 6,457 | 87.7% | 38.3 | 8,929 | 43.2 | 9942 | 48.3 | 11,252 | 67.1 | 16,740 | 98.29 | 89.7 |
| 60 | **25.4** | 6,379 | **87.9%** | **39.1** | 8,945 | **44.2** | 9991 | **49.4** | 11,282 | 68.6 | 16,769 | 97.26 | 89.7 |
| 61 | 25.6 | 6,332 | 88.0% | 39.5 | 8,870 | 45.2 | 10030 | 50.8 | 11,415 | 70.0 | 16,803 | 96.23 | 89.7 |
| 62 | 25.9 | 6,286 | 88.2% | 39.9 | 8,798 | 46.2 | 10068 | 52.3 | 11,543 | 71.4 | 16,834 | 95.21 | 89.7 |
| 63 | 26.1 | 6,242 | 88.3% | 40.3 | 8,728 | 47.2 | 10103 | 53.8 | 11,665 | 72.9 | 16,862 | 94.18 | 89.7 |
| 64 | 26.3 | 6,199 | 88.5% | 40.7 | 8,660 | 48.1 | 10137 | 55.3 | 11,783 | 74.3 | 16,889 | 93.15 | 89.7 |
| 65 | **26.6** | 6,158 | **88.6%** | **41.0** | 8,593 | **49.1** | 10169 | **56.8** | 11,896 | 75.7 | 16,913 | 92.12 | 89.7 |
| 66 | 26.9 | 6,132 | 88.7% | 41.8 | 8,614 | 49.8 | 10144 | 58.0 | 11,939 | 77.2 | 16,953 | 91.09 | 89.7 |
| 67 | 27.1 | 6,106 | 88.9% | 42.6 | 8,633 | 50.5 | 10120 | 59.2 | 11,980 | 78.7 | 16,992 | 90.07 | 89.7 |
| 68 | 27.4 | 6,082 | 89.0% | 43.4 | 8,652 | 51.3 | 10096 | 60.3 | 12,019 | 80.2 | 17,029 | 89.04 | 89.7 |
| 69 | 27.7 | 6,058 | 89.2% | 44.2 | 8,670 | 52.0 | 10073 | 61.5 | 12,056 | 81.7 | 17,063 | 88.01 | 89.7 |
| 70 | **28.0** | 6,035 | **89.3%** | **45.0** | 8,686 | **52.7** | 10050 | **62.7** | 12,092 | 83.2 | 17,096 | 86.98 | 89.7 |
| 71 | 28.3 | 6,012 | 89.4% | 45.8 | 8,693 | 53.6 | 10066 | 63.7 | 12,111 | 84.2 | 17,009 | 85.96 | 89.7 |
| 72 | 28.6 | 5,991 | 89.5% | 46.5 | 8,700 | 54.5 | 10081 | 64.5 | 12,067 | 85.1 | 16,920 | 84.93 | 89.7 |
| 73 | 28.9 | 5,970 | 89.5% | 47.2 | 8,706 | 55.3 | 10096 | 65.2 | 12,024 | 86.1 | 16,827 | 83.90 | 89.7 |
| 74 | 29.2 | 5,950 | 89.6% | 47.9 | 8,712 | 56.2 | 10110 | 65.9 | 11,982 | 87.0 | 16,733 | 82.87 | 89.7 |
| 75 | **29.5** | 5,930 | **89.7%** | **48.6** | 8,717 | **57.1** | 10124 | **68.0** | 12,179 | 87.9 | 16,635 | 81.85 | 89.7 |
| 76 | 29.8 | 5,913 | 89.8% | 49.1 | 8,673 | 57.8 | 10095 | 69.2 | 12,226 | 88.9 | 16,526 | 80.82 | 89.7 |
| 77 | 30.1 | 5,897 | 89.8% | 49.5 | 8,629 | 58.4 | 10066 | 70.4 | 12,270 | 89.9 | 16,416 | 79.79 | 89.7 |
| 78 | 30.4 | 5,881 | 89.9% | 49.9 | 8,587 | 59.0 | 10039 | 71.6 | 12,314 | 90.0 | 16,144 | 78.76 | 89.7 |
| 79 | 30.7 | 5,865 | 89.9% | 50.4 | 8,545 | 59.7 | 10011 | 72.8 | 12,356 | 90.0 | 15,863 | 77.73 | 89.7 |
| 80 | **31.1** | 5,850 | **90.0%** | **50.8** | 8,505 | **60.3** | 9985 | **74.0** | 12,396 | 90.0 | 15,589 | 76.71 | 89.7 |
| 81 | 31.4 | 5,845 | 90.0% | 51.4 | 8,493 | 60.6 | 9911 | 75.4 | 12,471 | 90.0 | 15,336 | 75.68 | 89.7 |
| 82 | 31.8 | 5,841 | 90.1% | 52.0 | 8,482 | 60.9 | 9840 | 76.8 | 12,543 | 90.0 | 15,091 | 74.65 | 89.7 |
| 83 | 32.1 | 5,836 | 90.1% | 52.5 | 8,471 | 61.3 | 9770 | 78.2 | 12,613 | 90.0 | 14,851 | 73.62 | 89.7 |
| 84 | 32.5 | 5,831 | 90.1% | 53.1 | 8,460 | 61.6 | 9702 | 79.6 | 12,681 | 90.0 | 14,618 | 72.60 | 89.7 |
| 85 | **32.9** | 5,827 | **90.2%** | **53.7** | 8,449 | **61.9** | 9635 | **81.0** | 12,748 | 90.0 | 14,391 | 72.00 | 89.7 |
| 86 | 33.3 | 5,831 | 90.2% | 54.3 | 8,441 | 63.1 | 9697 | 82.5 | 12,833 | 90.0 | 14,182 | 72.00 | 89.7 |
| 87 | 33.7 | 5,834 | 90.2% | 54.9 | 8,433 | 64.2 | 9758 | 84.0 | 12,916 | 90.0 | 13,978 | 72.00 | 89.7 |
| 88 | 34.1 | 5,838 | 90.2% | 55.5 | 8,425 | 65.3 | 9817 | 85.6 | 12,997 | 90.0 | 13,779 | 72.00 | 89.7 |
| 89 | 34.5 | 5,841 | 90.2% | 56.0 | 8,417 | 66.5 | 9876 | 87.1 | 13,076 | 90.0 | 13,585 | 72.00 | 89.7 |
| 90 | **34.9** | 5,845 | **90.2%** | **56.6** | 8,409 | **67.6** | 9932 | **88.6** | 13,154 | 90.0 | 13,395 | 72.00 | 89.7 |
| 91 | 35.4 | 5,855 | 90.2% | 57.3 | 8,411 | 68.5 | 9945 | 89.9 | 13,201 | 90.0 | 13,236 | 72.00 | 89.7 |
| 92 | 35.8 | 5,866 | 90.2% | 57.9 | 8,414 | 69.3 | 9957 | 91.2 | 13,248 | 90.0 | 13,080 | 72.00 | 89.7 |
| 93 | 36.3 | 5,876 | 90.2% | 58.6 | 8,416 | 70.1 | 9969 | 92.5 | 13,293 | 90.0 | 12,928 | 72.00 | 89.7 |
| 94 | 36.7 | 5,886 | 90.2% | 59.2 | 8,418 | 71.0 | 9980 | 93.8 | 13,338 | 90.0 | 12,779 | 72.00 | 89.7 |
| 95 | **37.2** | 5,896 | **90.2%** | **59.8** | 8,420 | **71.8** | 9991 | **95.1** | 13,381 | 90.0 | 12,634 | 72.00 | 89.7 |

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on turbine efficiency, gross head, and power output.
5. Turbine prototype efficiency at 1% below the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1954 Model Hill Curve cavitation limits with a 10' safety margin.
8. The tailwater is based on the CROHMS data between 1994-1998. The turbine operating limit is based on this minimum TW with a 10' SM.
9. The generator limit is based on 115% of generator nameplate of 82.105 MVA @ 0.95 pf = 89.7 MW.

Prepared by HDC, January 2001
RJW, DMW

## A.4.4.4 The Dalles Units 15 to 22 (No Screens Installed at this Project)

### Table A - 14. One percent table for The Dalles Units 15 to 22 with no screens installed

🟩 Maximum Power Output @ 1% 🟨 TW = -1.0277GH + 158.923 Gross Head to Tailwater Based on CROHMS

# The Dalles, Units 15-22, 1% Table with No Screens Installed

Based on the 1968 Model Test and 2001 NS Index Test on Unit 21.

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (ft) | (mW) |
| 55 | **29.0** | 7,936 | **87.5%** | **38.5** | 9,643 | **44.1** | 10923 | **49.3** | 12,346 | 71.7 | 18,942 | 102.40 | 98.9 |
| 56 | 29.3 | 7,894 | 87.8% | 39.0 | 9,554 | 44.5 | 10787 | 50.6 | 12,402 | 73.5 | 18,997 | 101.37 | 98.9 |
| 57 | 29.7 | 7,852 | 88.1% | 39.4 | 9,468 | 44.9 | 10656 | 51.9 | 12,454 | 75.2 | 19,049 | 100.34 | 98.9 |
| 58 | 30.1 | 7,813 | 88.4% | 39.9 | 9,384 | 45.3 | 10529 | 53.2 | 12,503 | 76.9 | 19,098 | 99.32 | 98.9 |
| 59 | 30.4 | 7,774 | 88.7% | 40.4 | 9,302 | 45.7 | 10406 | 54.4 | 12,548 | 78.7 | 19,145 | 98.29 | 98.9 |
| 60 | **30.8** | 7,737 | **88.9%** | **40.8** | 9,223 | **46.0** | 10286 | **55.7** | 12,590 | 80.5 | 19,189 | 97.26 | 98.9 |
| 61 | 31.2 | 7,709 | 89.1% | 41.6 | 9,219 | 47.4 | 10396 | 56.8 | 12,599 | 82.2 | 19,254 | 96.23 | 98.9 |
| 62 | 31.6 | 7,681 | 89.3% | 42.3 | 9,215 | 48.8 | 10502 | 57.9 | 12,607 | 83.9 | 19,316 | 95.21 | 98.9 |
| 63 | 32.0 | 7,654 | 89.4% | 43.0 | 9,211 | 50.1 | 10603 | 58.9 | 12,613 | 85.6 | 19,376 | 94.18 | 98.9 |
| 64 | 32.4 | 7,629 | 89.6% | 43.8 | 9,207 | 51.5 | 10700 | 60.0 | 12,619 | 87.3 | 19,433 | 93.15 | 98.9 |
| 65 | **32.8** | 7,604 | **89.7%** | **44.5** | 9,202 | **52.8** | 10794 | **61.1** | 12,624 | 89.0 | 19,488 | 92.12 | 98.9 |
| 66 | 33.2 | 7,573 | 89.8% | 45.1 | 9,164 | 54.2 | 10903 | 62.5 | 12,719 | 90.8 | 19,528 | 91.09 | 98.9 |
| 67 | 33.5 | 7,542 | 89.9% | 45.6 | 9,127 | 55.6 | 11009 | 64.0 | 12,810 | 92.5 | 19,566 | 90.07 | 98.9 |
| 68 | 33.9 | 7,513 | 90.0% | 46.1 | 9,091 | 57.0 | 11111 | 65.5 | 12,899 | 94.2 | 19,602 | 89.04 | 98.9 |
| 69 | 34.3 | 7,484 | 90.1% | 46.7 | 9,056 | 58.4 | 11210 | 66.9 | 12,984 | 95.9 | 19,636 | 88.01 | 98.9 |
| 70 | **34.6** | 7,457 | **90.1%** | **47.2** | 9,021 | **59.8** | 11305 | **68.4** | 13,066 | 97.6 | 19,667 | 86.98 | 98.9 |
| 71 | 35.0 | 7,423 | 90.2% | 47.9 | 9,019 | 61.0 | 11349 | 70.0 | 13,168 | 98.7 | 19,501 | 85.96 | 98.9 |
| 72 | 35.3 | 7,391 | 90.3% | 48.6 | 9,016 | 62.1 | 11391 | 70.6 | 13,105 | 98.7 | 19,141 | 84.93 | 98.9 |
| 73 | 35.6 | 7,359 | 90.3% | 49.3 | 9,014 | 63.2 | 11432 | 71.3 | 13,043 | 98.7 | 18,792 | 83.90 | 98.9 |
| 74 | 36.0 | 7,328 | 90.4% | 50.0 | 9,011 | 64.3 | 11471 | 72.0 | 12,983 | 98.7 | 18,453 | 82.87 | 98.9 |
| 75 | **36.3** | 7,298 | **90.4%** | **50.7** | 9,008 | **65.5** | 11509 | **76.2** | 13,542 | 98.7 | 18,123 | 81.85 | 98.9 |
| 76 | 36.7 | 7,281 | 90.5% | 51.3 | 8,984 | 66.8 | 11585 | 77.8 | 13,638 | 98.7 | 17,824 | 80.82 | 98.9 |
| 77 | 37.1 | 7,265 | 90.6% | 51.8 | 8,960 | 68.2 | 11659 | 79.4 | 13,731 | 98.7 | 17,532 | 79.79 | 98.9 |
| 78 | 37.5 | 7,248 | 90.6% | 52.4 | 8,936 | 69.5 | 11731 | 81.0 | 13,821 | 98.7 | 17,249 | 78.76 | 98.9 |
| 79 | 37.9 | 7,233 | 90.7% | 53.0 | 8,913 | 70.9 | 11800 | 82.6 | 13,908 | 98.7 | 16,973 | 77.73 | 98.9 |
| 80 | **38.3** | 7,217 | **90.7%** | **53.5** | 8,891 | **72.3** | 11868 | **84.3** | 13,993 | 98.7 | 16,704 | 76.71 | 98.9 |
| 81 | 38.7 | 7,198 | 90.7% | 54.2 | 8,896 | 73.1 | 11870 | 85.9 | 14,092 | 98.7 | 16,465 | 75.68 | 98.9 |
| 82 | 39.1 | 7,179 | 90.7% | 54.9 | 8,902 | 74.0 | 11871 | 87.5 | 14,188 | 98.7 | 16,231 | 74.65 | 98.9 |
| 83 | 39.4 | 7,161 | 90.7% | 55.6 | 8,908 | 74.9 | 11873 | 89.2 | 14,283 | 98.7 | 16,003 | 73.62 | 98.9 |
| 84 | 39.8 | 7,143 | 90.7% | 56.3 | 8,914 | 75.8 | 11874 | 90.8 | 14,375 | 98.7 | 15,781 | 72.60 | 98.9 |
| 85 | **40.2** | 7,126 | **90.6%** | **57.0** | 8,919 | **76.7** | 11876 | **92.4** | 14,465 | 98.7 | 15,564 | 72.0 | 98.9 |
| 86 | 40.6 | 7,110 | 90.6% | 57.5 | 8,898 | 78.1 | 11960 | 94.1 | 14,564 | 98.7 | 15,363 | 72.0 | 98.9 |
| 87 | 41.0 | 7,095 | 90.5% | 58.0 | 8,877 | 79.5 | 12042 | 95.8 | 14,660 | 98.7 | 15,166 | 72.0 | 98.9 |
| 88 | 41.3 | 7,080 | 90.5% | 58.5 | 8,856 | 80.9 | 12123 | 97.4 | 14,755 | 98.7 | 14,974 | 72.0 | 98.9 |
| 89 | 41.7 | 7,065 | 90.4% | 59.0 | 8,836 | 82.3 | 12202 | 99.1 | 14,848 | 98.7 | 14,786 | 72.0 | 98.9 |
| 90 | **42.1** | 7,051 | **90.3%** | **59.5** | 8,817 | **83.7** | 12280 | **100.8** | 14,939 | 98.7 | 14,602 | 72.0 | 98.9 |
| 91 | 42.4 | 7,029 | 90.3% | 60.1 | 8,815 | 84.9 | 12317 | 101.7 | 14,908 | 98.7 | 14,429 | 72.0 | 98.9 |
| 92 | 42.8 | 7,008 | 90.3% | 60.8 | 8,813 | 86.1 | 12353 | 102.6 | 14,878 | 98.7 | 14,260 | 72.0 | 98.9 |
| 93 | 43.1 | 6,987 | 90.3% | 61.4 | 8,811 | 87.3 | 12388 | 103.5 | 14,848 | 98.7 | 14,094 | 72.0 | 98.9 |
| 94 | 43.5 | 6,967 | 90.3% | 62.1 | 8,809 | 88.5 | 12423 | 104.4 | 14,819 | 98.7 | 13,932 | 72.0 | 98.9 |
| 95 | **43.8** | 6,947 | **90.3%** | **62.7** | 8,808 | **89.7** | 12457 | **105.3** | 14,790 | 98.7 | 13,773 | 72.0 | 98.9 |

Prepared by HDC, October 2002
RJW, DMW

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on turbine efficiency, gross head, and power output.
5. Turbine prototype efficiency at 1% below the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1968 Model Test cavitation limits with a 10' safety margin.
8. The tailwater is based on the CROHMS data between 1993-1998. The turbine operating limit is based on this minimum TW with a 10' SM.
9. The generator limit is based on 115% of generator nameplate. Nameplate is 90.500 MVA @ 0.95 pf = 85.98 MW.

## A.4.4.5 John Day Units 1 to 16

### Without Screens

**Table A - 15. One percent table for John Day Units 1 to 16 with no screens installed**

🟩 Maximum Power Output @ 1%

🟨 TW = -0.81GH + 242.56 Gross Head to Tailwater Based on CROHMS

## John Day, Units 1-16, 1% Table with No Screens Installed

### Based on the 1962 Model Test and 2001 Unit 9 NS Index Test

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (ft) | (mW) |
| 80 | **52.0** | 9,804 | **87.8%** | **71.7** | 12,305 | **101.4** | 17209 | **122.8** | 21,074 | 129.9 | 22,684 | 173.00 | 155.3 |
| 81 | 52.4 | 9,753 | 87.9% | 73.2 | 12,391 | 103.7 | 17369 | 125.7 | 21,290 | 132.1 | 22,697 | 173.00 | 155.3 |
| 82 | 52.8 | 9,703 | 88.0% | 74.7 | 12,473 | 106.1 | 17524 | 128.7 | 21,500 | 134.3 | 22,710 | 173.00 | 155.3 |
| 83 | 53.2 | 9,655 | 88.1% | 76.1 | 12,554 | 108.4 | 17675 | 131.6 | 21,703 | 136.5 | 22,720 | 173.00 | 155.3 |
| 84 | 53.6 | 9,607 | 88.2% | 77.6 | 12,631 | 110.8 | 17821 | 134.6 | 21,901 | 138.7 | 22,730 | 173.00 | 155.3 |
| 85 | **53.9** | 9,561 | **88.3%** | **79.1** | 12,707 | **113.1** | 17963 | **137.5** | 22,093 | 140.9 | 22,738 | 173.00 | 155.3 |
| 86 | 54.5 | 9,542 | 88.4% | 80.0 | 12,690 | 114.9 | 18030 | 140.1 | 22,223 | 142.7 | 22,722 | 172.90 | 155.3 |
| 87 | 55.0 | 9,523 | 88.4% | 80.9 | 12,674 | 116.8 | 18096 | 142.6 | 22,349 | 144.5 | 22,704 | 172.09 | 155.3 |
| 88 | 55.5 | 9,505 | 88.5% | 81.7 | 12,657 | 118.6 | 18160 | 145.1 | 22,471 | 146.2 | 22,684 | 171.28 | 155.3 |
| 89 | 56.0 | 9,488 | 88.5% | 82.6 | 12,641 | 120.4 | 18222 | 147.6 | 22,591 | 148.0 | 22,662 | 170.47 | 155.3 |
| 90 | **56.6** | 9,470 | **88.6%** | **83.5** | 12,625 | **122.3** | 18283 | **150.2** | 22,707 | 149.7 | 22,638 | 169.66 | 155.3 |
| 91 | 57.0 | 9,436 | 88.7% | 84.5 | 12,616 | 123.6 | 18250 | 151.7 | 22,656 | 151.1 | 22,562 | 168.85 | 155.3 |
| 92 | 57.4 | 9,403 | 88.8% | 85.5 | 12,606 | 124.9 | 18217 | 153.2 | 22,606 | 152.5 | 22,484 | 168.04 | 155.3 |
| 93 | 57.8 | 9,370 | 89.0% | 86.4 | 12,596 | 126.2 | 18185 | 154.8 | 22,556 | 153.8 | 22,403 | 167.23 | 155.3 |
| 94 | 58.2 | 9,338 | 89.1% | 87.4 | 12,586 | 127.5 | 18153 | 156.3 | 22,507 | 155.1 | 22,321 | 166.42 | 155.3 |
| 95 | **58.7** | 9,306 | **89.2%** | **88.4** | 12,576 | **128.8** | 18121 | **157.8** | 22,459 | 155.2 | 22,062 | 165.61 | 155.3 |
| 96 | 59.2 | 9,299 | 89.3% | 89.6 | 12,597 | 129.5 | 18006 | 158.2 | 22,243 | 155.2 | 21,797 | 164.80 | 155.3 |
| 97 | 59.8 | 9,292 | 89.4% | 90.8 | 12,617 | 130.2 | 17893 | 158.5 | 22,032 | 155.2 | 21,538 | 163.99 | 155.3 |
| 98 | 60.4 | 9,285 | 89.5% | 92.0 | 12,636 | 130.9 | 17783 | 158.8 | 21,826 | 155.2 | 21,284 | 163.18 | 155.3 |
| 99 | 61.0 | 9,278 | 89.6% | 93.1 | 12,655 | 131.5 | 17674 | 159.2 | 21,623 | 155.2 | 21,035 | 162.37 | 155.3 |
| 100 | **61.5** | 9,271 | **89.7%** | **94.3** | 12,673 | **132.2** | 17567 | **159.5** | 21,425 | 155.2 | 20,792 | 161.56 | 155.3 |
| 101 | 62.1 | 9,263 | 89.8% | 95.3 | 12,675 | 134.0 | 17616 | 161.8 | 21,507 | 155.2 | 20,554 | 160.75 | 155.3 |
| 102 | 62.6 | 9,254 | 89.8% | 96.4 | 12,676 | 135.8 | 17663 | 164.1 | 21,587 | 155.2 | 20,321 | 159.94 | 155.3 |
| 103 | 63.2 | 9,246 | 89.9% | 97.4 | 12,678 | 137.5 | 17708 | 166.4 | 21,666 | 155.2 | 20,092 | 159.13 | 155.3 |
| 104 | 63.8 | 9,237 | 89.9% | 98.4 | 12,679 | 139.3 | 17753 | 168.7 | 21,742 | 155.2 | 19,868 | 158.32 | 155.3 |
| 105 | **64.3** | 9,229 | **90.0%** | **99.4** | 12,680 | **141.0** | 17797 | **171.0** | 21,817 | 155.2 | 19,649 | 157.51 | 155.3 |
| 106 | 64.9 | 9,228 | 90.0% | 100.2 | 12,656 | 142.3 | 17778 | 172.6 | 21,801 | 155.2 | 19,442 | 156.70 | 155.3 |
| 107 | 65.5 | 9,226 | 90.1% | 101.0 | 12,633 | 143.6 | 17759 | 174.2 | 21,785 | 155.2 | 19,239 | 155.89 | 155.3 |
| 108 | 66.1 | 9,225 | 90.1% | 101.8 | 12,610 | 144.8 | 17740 | 175.8 | 21,768 | 155.2 | 19,040 | 155.08 | 155.3 |
| 109 | 66.7 | 9,223 | 90.2% | 102.6 | 12,587 | 146.1 | 17722 | 177.4 | 21,752 | 155.2 | 18,845 | 154.27 | 155.3 |
| 110 | **67.3** | 9,222 | **90.2%** | **103.5** | 12,565 | **147.4** | 17703 | **179.0** | 21,736 | 155.2 | 18,653 | 153.46 | 155.3 |

Prepared by HDC, November 2002
RJW, DMW

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on turbine efficiency, gross head, and power output.
5. Turbine prototype efficiency at 1% below the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1962 Model Test cavitation limits with a 5.5 foot safety margin.
8. The tailwater is based on the CROHMS data between 1993-1998. The turbine operating limit is based on this minimum TW with a 5.5 foot SM.
9. The generator limit is based on 115% of generator nameplate. Nameplate is142.105 MVA @ 0.95 pf = 135.0 MW.

With Fish Screens

## Table A - 16. One percent table for John Day Units 1 to 16 with STS installed

🟩 Maximum Power Output @ 1%

🟨 TW = -0.81GH + 242.56 Gross Head to Tailwater Based on CROHMS

# John Day, Units 1-16, 1% Table with STS Installed

## Based on the 1962 Model Test and 2001 Unit 9 STS Index Test with STS adjustment Factor

| [1]Gross | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested | Turbine Discharge | [8]CROHMS | [9]Gen. Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Head | [3]Generator Power | [4]Discharge | 1% Limit Expected eff. | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | Operating Limit | @Limit | Minimum Tailwater | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (ft) | (mW) |
| 80 | **51.8** | 9,748 | **86.9%** | **65.4** | 11,338 | **94.9** | 16266 | **118.0** | 20,472 | 129.9 | 23,194 | 173.00 | 155.3 |
| 81 | 52.1 | 9,698 | 87.0% | 66.7 | 11,416 | 97.0 | 16410 | 120.8 | 20,671 | 132.1 | 23,228 | 173.00 | 155.3 |
| 82 | 52.5 | 9,648 | 87.1% | 68.1 | 11,492 | 99.2 | 16551 | 123.6 | 20,864 | 134.3 | 23,261 | 173.00 | 155.3 |
| 83 | 52.9 | 9,600 | 87.2% | 69.4 | 11,566 | 101.3 | 16687 | 126.4 | 21,052 | 136.5 | 23,292 | 173.00 | 155.3 |
| 84 | 53.2 | 9,553 | 87.3% | 70.8 | 11,638 | 103.5 | 16819 | 129.1 | 21,234 | 138.7 | 23,321 | 173.00 | 155.3 |
| 85 | **53.6** | 9,507 | **87.4%** | **72.1** | 11,707 | **105.6** | 16947 | **131.9** | 21,411 | 140.9 | 23,349 | 173.00 | 155.3 |
| 86 | 54.1 | 9,488 | 87.4% | 72.9 | 11,692 | 107.5 | 17041 | 134.7 | 21,593 | 142.7 | 23,282 | 172.90 | 155.3 |
| 87 | 54.7 | 9,469 | 87.5% | 73.7 | 11,676 | 109.4 | 17133 | 137.5 | 21,770 | 144.5 | 23,214 | 172.09 | 155.3 |
| 88 | 55.2 | 9,451 | 87.6% | 74.5 | 11,661 | 111.3 | 17222 | 140.2 | 21,942 | 146.2 | 23,145 | 171.28 | 155.3 |
| 89 | 55.7 | 9,434 | 87.6% | 75.3 | 11,646 | 113.2 | 17308 | 143.0 | 22,110 | 148.0 | 23,074 | 170.47 | 155.3 |
| 90 | **56.2** | 9,417 | **87.7%** | **76.1** | 11,632 | **115.1** | 17393 | **145.8** | 22,274 | 149.7 | 23,001 | 169.66 | 155.3 |
| 91 | 56.7 | 9,383 | 87.8% | 77.0 | 11,622 | 116.1 | 17329 | 146.9 | 22,164 | 151.1 | 22,917 | 168.85 | 155.3 |
| 92 | 57.1 | 9,349 | 87.9% | 77.9 | 11,613 | 117.2 | 17265 | 148.0 | 22,057 | 152.5 | 22,831 | 168.04 | 155.3 |
| 93 | 57.5 | 9,316 | 88.0% | 78.8 | 11,604 | 118.2 | 17203 | 149.1 | 21,951 | 153.8 | 22,743 | 167.23 | 155.3 |
| 94 | 57.9 | 9,285 | 88.2% | 79.7 | 11,595 | 119.2 | 17142 | 150.2 | 21,848 | 155.1 | 22,652 | 166.42 | 155.3 |
| 95 | **58.3** | 9,253 | **88.3%** | **80.6** | 11,585 | **120.2** | 17082 | **151.3** | 21,746 | 155.2 | 22,383 | 165.61 | 155.3 |
| 96 | 58.9 | 9,246 | 88.4% | 81.7 | 11,604 | 120.8 | 16972 | 151.6 | 21,532 | 155.2 | 22,115 | 164.80 | 155.3 |
| 97 | 59.5 | 9,239 | 88.5% | 82.8 | 11,623 | 121.4 | 16864 | 151.8 | 21,323 | 155.2 | 21,852 | 163.99 | 155.3 |
| 98 | 60.0 | 9,232 | 88.6% | 83.8 | 11,640 | 122.1 | 16759 | 152.1 | 21,118 | 155.2 | 21,595 | 163.18 | 155.3 |
| 99 | 60.6 | 9,225 | 88.7% | 84.9 | 11,657 | 122.7 | 16655 | 152.4 | 20,917 | 155.2 | 21,343 | 162.37 | 155.3 |
| 100 | **61.2** | 9,219 | **88.8%** | **86.0** | 11,674 | **123.3** | 16553 | **152.7** | 20,720 | 155.2 | 21,096 | 161.56 | 155.3 |
| 101 | 61.7 | 9,210 | 88.9% | 86.9 | 11,675 | 125.0 | 16598 | 154.9 | 20,800 | 155.2 | 20,852 | 160.75 | 155.3 |
| 102 | 62.3 | 9,202 | 88.9% | 87.9 | 11,677 | 126.6 | 16642 | 157.1 | 20,877 | 155.2 | 20,613 | 159.94 | 155.3 |
| 103 | 62.8 | 9,193 | 89.0% | 88.8 | 11,678 | 128.3 | 16685 | 159.3 | 20,953 | 155.2 | 20,378 | 159.13 | 155.3 |
| 104 | 63.4 | 9,185 | 89.0% | 89.7 | 11,679 | 129.9 | 16726 | 161.5 | 21,027 | 155.2 | 20,149 | 158.32 | 155.3 |
| 105 | **63.9** | 9,177 | **89.1%** | **90.6** | 11,680 | **131.5** | 16767 | **163.7** | 21,100 | 155.2 | 19,923 | 157.51 | 155.3 |
| 106 | 64.5 | 9,175 | 89.1% | 91.4 | 11,658 | 132.7 | 16748 | 165.2 | 21,084 | 155.2 | 19,711 | 156.70 | 155.3 |
| 107 | 65.1 | 9,174 | 89.2% | 92.1 | 11,637 | 133.9 | 16730 | 166.7 | 21,068 | 155.2 | 19,503 | 155.89 | 155.3 |
| 108 | 65.7 | 9,172 | 89.2% | 92.8 | 11,615 | 135.1 | 16713 | 168.3 | 21,052 | 155.2 | 19,299 | 155.08 | 155.3 |
| 109 | 66.3 | 9,171 | 89.3% | 93.6 | 11,594 | 136.3 | 16695 | 169.8 | 21,036 | 155.2 | 19,098 | 154.27 | 155.3 |
| 110 | **66.9** | 9,170 | **89.3%** | **94.3** | 11,574 | **137.5** | 16677 | **171.3** | 21,021 | 155.2 | 18,901 | 153.46 | 155.3 |

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on turbine efficiency, gross head, and power output.
5. Turbine prototype efficiency at 1% below the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1962 Model Test cavitation limits with a 5.5 foot safety margin.
8. The tailwater is based on the CROHMS data between 1993-1998. The turbine operating limit is based on this minimum TW with a 5.5 foot SM.
9. The generator limit is based on 115% of generator nameplate. Nameplate is142.105 MVA @ 0.95 pf = 135.0 MW.

Prepared by HDC, November 2002
RJW, DMW

## A.4.4.6 McNary Units 1 to 14

### Without Screens

**Table A - 17. One percent table for McNary Units 1 to 14 with no screens installed**

🟩 Maximum Power Output @ 1%

🟨 T = -0.9057GH + 333.754 Gross Head to Tailwater Based on CROHMS

### McNary, U1-14, 1% Table with No Screens Installed

Based on the 1998 Index Test and the 1955 Model Hill Curve

| [1]Gross Head | [2]Lower Limit @ 80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit Generator | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit 115% All Units |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (fmsl) | (mW) |
| 62 | **23.8** | 5785 | **87.0%** | **34.7** | 7,754 | **40.7** | 9,092 | **50.8** | 11,346 | 68.0 | 16,034 | 274.81 | 84.7 |
| 63 | 24.2 | 5790 | 87.1% | 35.4 | 7,765 | 41.3 | 9,078 | 52.1 | 11,444 | 69.6 | 16,134 | 273.86 | 84.7 |
| 64 | 24.6 | 5795 | 87.3% | 36.0 | 7,776 | 42.0 | 9,065 | 53.5 | 11,537 | 71.2 | 16,233 | 272.91 | 84.7 |
| 65 | **25.0** | 5,799 | **87.4%** | **36.7** | 7,786 | **42.7** | 8,949 | **54.8** | 11,627 | 72.8 | 16,331 | 271.96 | 84.7 |
| 66 | 25.4 | 5,791 | 87.5% | 37.2 | 7,762 | 44.2 | 9,125 | 56.3 | 11,759 | 74.1 | 16,342 | 271.01 | 84.7 |
| 67 | 25.7 | 5,783 | 87.6% | 37.7 | 7,739 | 45.8 | 9,295 | 57.9 | 11,887 | 75.3 | 16,350 | 270.06 | 84.7 |
| 68 | 26.1 | 5,775 | 87.7% | 38.2 | 7,716 | 47.3 | 9,460 | 59.4 | 12,009 | 76.6 | 16,356 | 269.11 | 84.7 |
| 69 | 26.4 | 5,767 | 87.8% | 38.7 | 7,694 | 48.9 | 9,620 | 60.9 | 12,128 | 77.8 | 16,360 | 268.16 | 84.7 |
| 70 | **26.8** | 5,760 | **87.9%** | **39.2** | 7,671 | **50.5** | 9,774 | **62.5** | 12,243 | 79.0 | 16,361 | 267.21 | 84.7 |
| 71 | 27.3 | 5,784 | 88.0% | 39.8 | 7,681 | 51.3 | 9,794 | 63.4 | 12,243 | 79.7 | 16,153 | 266.25 | 84.7 |
| 72 | 27.7 | 5,807 | 88.1% | 40.4 | 7,691 | 52.2 | 9,813 | 64.4 | 12,242 | 80.4 | 15,944 | 265.30 | 84.7 |
| 73 | 28.2 | 5,830 | 88.1% | 41.1 | 7,699 | 53.1 | 9,831 | 65.3 | 12,241 | 81.0 | 15,734 | 264.35 | 84.7 |
| 74 | 28.7 | 5,852 | 88.2% | 41.7 | 7,708 | 53.9 | 9,849 | 66.3 | 12,240 | 81.6 | 15,524 | 263.40 | 84.7 |
| 75 | **29.2** | 5,873 | **88.3%** | **42.4** | 7,716 | **54.8** | 9,865 | **67.2** | 12,239 | 82.2 | 15,313 | 262.45 | 84.7 |
| 76 | 29.7 | 5,894 | 88.4% | 43.0 | 7,714 | 55.5 | 9,841 | 67.9 | 12,172 | 82.5 | 15,154 | 261.50 | 84.7 |
| 77 | 30.2 | 5,915 | 88.5% | 43.6 | 7,713 | 56.1 | 9,817 | 68.5 | 12,107 | 82.8 | 14,992 | 260.55 | 84.7 |
| 78 | 30.7 | 5,935 | 88.7% | 44.2 | 7,711 | 56.8 | 9,794 | 69.1 | 12,043 | 83.1 | 14,826 | 259.60 | 84.7 |
| 79 | 31.2 | 5,955 | 88.8% | 44.8 | 7,709 | 57.5 | 9,770 | 69.7 | 11,980 | 83.3 | 14,656 | 258.65 | 84.7 |
| 80 | **31.7** | 5,974 | **88.9%** | **45.5** | 7,706 | **58.2** | 9,747 | **70.3** | 11,920 | 83.4 | 14,484 | 257.70 | 84.7 |
| 81 | 32.3 | 6,003 | 88.9% | 46.1 | 7,720 | 59.0 | 9,760 | 71.5 | 11,961 | 83.7 | 14,310 | 256.75 | 84.7 |
| 82 | 32.8 | 6,030 | 88.9% | 46.8 | 7,734 | 59.8 | 9,772 | 72.6 | 12,000 | 83.8 | 14,133 | 255.80 | 84.7 |
| 83 | 33.4 | 6,058 | 89.0% | 47.4 | 7,747 | 60.6 | 9,784 | 73.7 | 12,038 | 84.0 | 13,955 | 254.85 | 84.7 |
| 84 | 33.9 | 6,084 | 89.0% | 48.1 | 7,759 | 61.4 | 9,795 | 74.9 | 12,076 | 84.1 | 13,773 | 253.90 | 84.7 |
| 85 | **34.5** | 6,110 | **89.0%** | **48.8** | 7,772 | **62.2** | 9,806 | **76.0** | 12,112 | 84.2 | 13,589 | 252.94 | 84.7 |
| 86 | 35.0 | 6,137 | 89.0% | 49.5 | 7,794 | 63.0 | 9,816 | 76.7 | 12,073 | 84.0 | 13,382 | 251.99 | 84.7 |
| 87 | 35.6 | 6,164 | 89.0% | 50.2 | 7,815 | 63.8 | 9,825 | 77.3 | 12,034 | 83.8 | 13,172 | 251.04 | 84.7 |
| 88 | 36.1 | 6,189 | 89.1% | 50.9 | 7,836 | 64.7 | 9,834 | 78.0 | 11,996 | 83.5 | 12,959 | 250.09 | 84.7 |
| 89 | 36.7 | 6,214 | 89.1% | 51.7 | 7,856 | 65.5 | 9,843 | 78.7 | 11,960 | 83.2 | 12,743 | 249.14 | 84.7 |
| 90 | **37.3** | 6,239 | **89.1%** | **52.4** | 7,875 | **66.3** | 9,852 | **79.3** | 11,923 | 82.8 | 12,525 | 248.19 | 84.7 |
| 91 | 37.9 | 6,274 | 89.1% | 53.2 | 7,903 | 67.1 | 9,865 | 80.0 | 11,894 | 82.5 | 12,314 | 247.24 | 84.7 |
| 92 | **38.5** | 6,308 | **89.1%** | **53.9** | 7,930 | **67.9** | 9,877 | **80.7** | 11,865 | 82.1 | 12,101 | 246.29 | 84.7 |

Prepared by HDC, March 1999
RJW, DMW

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on model efficiency, gross head, and power output.
5. Turbine model efficiency at a 1% drop from the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1955 Model Hill Curve cavitation limits with a 10' safety margin.
8. The tailwater is based on the CROHMS data between 1990-1997. The turbine operating limit is based on this min TW with a 10' SM.
9. The generator limit is based on 115% of generator nameplate KVA at unity power factor.

With Fish Screens

### Table A - 18. One percent table for McNary Units 1 to 14 with ESBS installed

🟩 Maximum Power Output

🟨 T = -0.9057GH + 333.754 Gross Head to Tailwater Based on CROHMS

## McNary U1-14 ESBS

Based on the 1998 Index test and the 1955 Prototype Hill Curve with ESBS Adjustment Factors

| [1]Gross Head | [2]Lower Limit '@ 80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit 115% All Units |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (fmsl) | (mW) |
| 62 | **28.0** | 6,797 | **84.4%** | **34.5** | 7,951 | **40.2** | 9,155 | **49.7** | 11,454 | 68.0 | 16,515 | 274.81 | 84.7 |
| 63 | 28.4 | 6,803 | 84.5% | 35.2 | 7,963 | 40.9 | 9,143 | 51.0 | 11,552 | 69.6 | 16,631 | 273.86 | 84.7 |
| 64 | 28.9 | 6,809 | 84.7% | 35.8 | 7,974 | 41.5 | 9,131 | 52.3 | 11,646 | 71.2 | 16,747 | 272.91 | 84.7 |
| 65 | **29.4** | 6,814 | **84.8%** | **36.5** | 7,984 | **42.2** | 9,119 | **53.7** | 11,736 | 72.8 | 16,861 | 271.96 | 84.7 |
| 66 | 29.8 | 6,804 | 84.9% | 37.0 | 7,959 | 43.7 | 9,293 | 55.2 | 11,869 | 74.1 | 16,871 | 271.01 | 84.7 |
| 67 | 30.2 | 6,795 | 85.0% | 37.5 | 7,934 | 45.2 | 9,462 | 56.7 | 11,997 | 75.3 | 16,879 | 270.06 | 84.7 |
| 68 | 30.6 | 6,786 | 85.1% | 38.0 | 7,911 | 46.7 | 9,625 | 58.2 | 12,121 | 76.6 | 16,885 | 269.11 | 84.7 |
| 69 | 31.0 | 6,777 | 85.2% | 38.5 | 7,887 | 48.3 | 9,783 | 59.7 | 12,240 | 77.8 | 16,888 | 268.16 | 84.7 |
| 70 | **31.4** | 6,768 | **85.3%** | **39.0** | 7,864 | **49.8** | 9,935 | **61.2** | 12,355 | 79.0 | 16,889 | 267.21 | 84.7 |
| 71 | 32.0 | 6,796 | 85.4% | 39.6 | 7,874 | 50.8 | 9,984 | 62.1 | 12,355 | 79.7 | 16,690 | 266.25 | 84.7 |
| 72 | 32.6 | 6,823 | 85.5% | 40.2 | 7,883 | 51.8 | 10,030 | 62.8 | 12,298 | 80.4 | 16,490 | 265.30 | 84.7 |
| 73 | 33.2 | 6,850 | 85.5% | 40.9 | 7,892 | 52.8 | 10,076 | 63.4 | 12,242 | 81.0 | 16,289 | 264.35 | 84.7 |
| 74 | 33.8 | 6,876 | 85.6% | 41.5 | 7,901 | 53.8 | 10,119 | 64.1 | 12,188 | 81.6 | 16,087 | 263.40 | 84.7 |
| 75 | **34.3** | 6,901 | **85.7%** | **42.2** | 7,909 | **54.8** | 10,161 | **65.8** | 12,350 | 82.2 | 15,883 | 262.45 | 84.7 |
| 76 | 34.9 | 6,926 | 85.8% | 42.8 | 7,907 | 55.3 | 10,107 | 66.4 | 12,282 | 82.5 | 15,699 | 261.50 | 84.7 |
| 77 | 35.5 | 6,950 | 85.9% | 43.4 | 7,905 | 55.8 | 10,054 | 67.1 | 12,216 | 82.8 | 15,512 | 260.55 | 84.7 |
| 78 | 36.1 | 6,974 | 86.1% | 44.0 | 7,903 | 56.3 | 10,002 | 67.7 | 12,151 | 83.1 | 15,321 | 259.60 | 84.7 |
| 79 | 36.7 | 6,997 | 86.2% | 44.6 | 7,900 | 56.9 | 9,952 | 68.3 | 12,088 | 83.3 | 15,128 | 258.65 | 84.7 |
| 80 | **37.3** | 7,019 | **86.3%** | **45.2** | 7,897 | **57.4** | 9,902 | **68.9** | 12,026 | 83.4 | 14,931 | 257.70 | 84.7 |
| 81 | 37.9 | 7,053 | 86.5% | 45.9 | 7,893 | 58.2 | 9,892 | 70.0 | 12,039 | 83.7 | 14,753 | 256.75 | 84.7 |
| 82 | 38.6 | 7,086 | 86.7% | 46.5 | 7,889 | 59.0 | 9,882 | 71.1 | 12,050 | 83.8 | 14,571 | 255.80 | 84.7 |
| 83 | 39.2 | 7,118 | 87.0% | 47.2 | 7,884 | 59.8 | 9,872 | 72.2 | 12,061 | 84.0 | 14,387 | 254.85 | 84.7 |
| 84 | 39.9 | 7,149 | 87.2% | 47.9 | 7,879 | 60.6 | 9,862 | 73.3 | 12,070 | 84.1 | 14,201 | 253.90 | 84.7 |
| 85 | **40.5** | 7,180 | **87.4%** | **48.5** | 7,873 | **61.4** | 9,851 | **74.4** | 12,079 | 84.2 | 14,012 | 252.94 | 84.7 |
| 86 | 41.2 | 7,211 | 87.4% | 49.2 | 7,895 | 62.2 | 9,860 | 75.1 | 12,040 | 84.0 | 13,799 | 251.99 | 84.7 |
| 87 | 41.8 | 7,242 | 87.4% | 50.0 | 7,917 | 63.0 | 9,869 | 75.7 | 12,001 | 83.8 | 13,583 | 251.04 | 84.7 |
| 88 | 42.5 | 7,272 | 87.5% | 50.7 | 7,938 | 63.8 | 9,877 | 76.4 | 11,964 | 83.5 | 13,364 | 250.09 | 84.7 |
| 89 | 43.1 | 7,302 | 87.5% | 51.4 | 7,958 | 64.6 | 9,886 | 77.0 | 11,927 | 83.2 | 13,143 | 249.14 | 84.7 |
| 90 | **43.8** | 7,331 | **87.5%** | **52.1** | 7,978 | **65.4** | 9,894 | **77.7** | 11,891 | 82.8 | 12,919 | 248.19 | 84.7 |
| 91 | 44.5 | 7,372 | 87.0% | 52.9 | 8,052 | 66.2 | 9,963 | 78.3 | 11,929 | 82.5 | 12,701 | 247.24 | 84.7 |
| 92 | **45.2** | 7,412 | **86.5%** | **53.6** | 8,127 | **67.0** | 10,032 | **79.0** | 11,969 | 82.1 | 12,480 | 246.29 | 84.7 |

Prepared by HDC, March 1999
RJW, DMW

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on model efficiency, gross head, and power output.
5. Turbine model efficiency at a 1% drop from the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1955 Model Hill Curve cavitation limits with a 10' safety margin.
8. The tailwater is based on the CROHMS data between 1990-1997. The turbine operating limit is based on this min TW with a 10' SM.
9. The generator limit is based on 115% of generator nameplate KVA at unity power factor.

## A.4.4.7 Lower Monumental Units 1 to 3

Without Screens

**Table A - 19. One percent table for Lower Monumental Units 1 to 3 with no screens installed**

🟩 Maximum Power Output @ 1%

🟨 TW = -GH + 537.55 Gross Head to Tailwater Based on CROHMS

# Lower Monumental, Units 1-3, 1% Table with No Screens Installed

Based on the 1962 Model Test and 2002 Unit 2 NS Index Test

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. [3]Generator Power | [4]Discharge | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit Generator Power | Discharge | [6]Best Turbine Operating Efficiency Generator Power | Discharge | Upper 1% Limit Generator Power | Discharge | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (ft) | (mW) |
| 80 | **53.8** | 10,131 | **87.8%** | **62.8** | 10,772 | **92.3** | 15,671 | **112.1** | 19,234 | 129.9 | 23,249 | 449.00 | 155.3 |
| 81 | 54.2 | 10,078 | 87.9% | 64.1 | 10,846 | 94.5 | 15,824 | 114.8 | 19,442 | 132.1 | 23,317 | 449.00 | 155.3 |
| 82 | 54.6 | 10,027 | 88.0% | 65.4 | 10,919 | 96.7 | 15,972 | 117.6 | 19,644 | 134.3 | 23,382 | 449.00 | 155.3 |
| 83 | 55.0 | 9,977 | 88.1% | 66.6 | 10,989 | 98.9 | 16,117 | 120.3 | 19,840 | 136.5 | 23,446 | 449.00 | 155.3 |
| 84 | 55.3 | 9,928 | 88.2% | 67.9 | 11,057 | 101.0 | 16,257 | 123.1 | 20,031 | 138.7 | 23,508 | 449.00 | 155.3 |
| 85 | **55.7** | 9,880 | **88.3%** | **69.2** | 11,123 | **103.2** | 16,393 | **125.8** | 20,216 | 140.9 | 23,569 | 449.00 | 155.3 |
| 86 | 56.3 | 9,860 | 88.4% | 70.0 | 11,109 | 105.0 | 16,475 | 128.3 | 20,363 | 142.8 | 23,542 | 449.00 | 155.3 |
| 87 | 56.8 | 9,841 | 88.4% | 70.8 | 11,094 | 106.8 | 16,554 | 130.8 | 20,506 | 144.6 | 23,513 | 449.00 | 155.3 |
| 88 | 57.4 | 9,822 | 88.5% | 71.6 | 11,080 | 108.6 | 16,631 | 133.3 | 20,645 | 146.5 | 23,482 | 449.00 | 155.3 |
| 89 | 57.9 | 9,804 | 88.5% | 72.3 | 11,066 | 110.4 | 16,706 | 135.8 | 20,781 | 148.3 | 23,450 | 448.55 | 155.3 |
| 90 | **58.4** | 9,786 | **88.6%** | **73.1** | 11,052 | **112.2** | 16,779 | **138.3** | 20,913 | 150.2 | 23,415 | 447.55 | 155.3 |
| 91 | 58.9 | 9,751 | 88.7% | 74.0 | 11,043 | 112.8 | 16,658 | 138.7 | 20,714 | 151.5 | 23,268 | 446.55 | 155.3 |
| 92 | 59.3 | 9,716 | 88.8% | 74.8 | 11,035 | 113.4 | 16,539 | 139.1 | 20,518 | 152.8 | 23,119 | 445.55 | 155.3 |
| 93 | 59.8 | 9,682 | 89.0% | 75.7 | 11,026 | 114.0 | 16,422 | 139.5 | 20,327 | 154.0 | 22,968 | 444.55 | 155.3 |
| 94 | 60.2 | 9,649 | 89.1% | 76.5 | 11,017 | 114.5 | 16,308 | 139.9 | 20,140 | 155.2 | 22,850 | 443.55 | 155.3 |
| 95 | **60.6** | 9,616 | **89.2%** | **77.4** | 11,009 | **115.1** | 16,196 | **140.3** | 19,956 | 155.2 | 22,409 | 442.55 | 155.3 |
| 96 | 61.2 | 9,609 | 89.3% | 78.4 | 11,027 | 115.6 | 16,078 | 140.4 | 19,746 | 155.2 | 22,125 | 441.55 | 155.3 |
| 97 | 61.8 | 9,602 | 89.4% | 79.5 | 11,044 | 116.1 | 15,963 | 140.6 | 19,540 | 155.2 | 21,847 | 440.55 | 155.3 |
| 98 | 62.4 | 9,595 | 89.5% | 80.5 | 11,061 | 116.6 | 15,851 | 140.7 | 19,338 | 155.2 | 21,576 | 439.55 | 155.3 |
| 99 | 63.0 | 9,588 | 89.6% | 81.5 | 11,078 | 117.1 | 15,740 | 140.9 | 19,141 | 155.2 | 21,309 | 438.55 | 155.3 |
| 100 | **63.6** | 9,581 | **89.7%** | **82.6** | 11,093 | **117.7** | 15,631 | **141.0** | 18,947 | 155.2 | 21,049 | 437.55 | 155.3 |
| 101 | 64.2 | 9,572 | 89.8% | 83.5 | 11,095 | 119.1 | 15,662 | 142.9 | 18,998 | 155.2 | 20,798 | 436.55 | 155.3 |
| 102 | 64.7 | 9,563 | 89.8% | 84.3 | 11,096 | 120.6 | 15,692 | 144.8 | 19,047 | 155.2 | 20,553 | 436.00 | 155.3 |
| 103 | 65.3 | 9,554 | 89.9% | 85.2 | 11,098 | 122.1 | 15,721 | 146.7 | 19,095 | 155.2 | 20,312 | 436.00 | 155.3 |
| 104 | 65.9 | 9,546 | 89.9% | 86.1 | 11,099 | 123.6 | 15,750 | 148.5 | 19,142 | 155.2 | 20,077 | 436.00 | 155.3 |
| 105 | **66.5** | 9,537 | **90.0%** | **87.0** | 11,100 | **125.0** | 15,777 | **150.4** | 19,188 | 155.2 | 19,846 | 436.00 | 155.3 |
| 106 | 67.1 | 9,536 | 90.0% | 87.7 | 11,079 | 126.2 | 15,761 | 151.8 | 19,173 | 155.2 | 19,632 | 436.00 | 155.3 |
| 107 | 67.7 | 9,534 | 90.1% | 88.4 | 11,059 | 127.3 | 15,744 | 153.2 | 19,159 | 155.2 | 19,423 | 436.00 | 155.3 |
| 108 | 68.3 | 9,533 | 90.1% | 89.1 | 11,038 | 128.4 | 15,728 | 154.6 | 19,145 | 155.2 | 19,217 | 436.00 | 155.3 |
| 109 | 68.9 | 9,531 | 90.2% | 89.9 | 11,019 | 129.5 | 15,712 | 156.0 | 19,131 | 155.2 | 19,016 | 436.00 | 155.3 |
| 110 | **69.6** | 9,530 | **90.2%** | **90.6** | 10,999 | **130.7** | 15,696 | **157.4** | 19,116 | 155.2 | 18,818 | 436.00 | 155.3 |

Prepared by HDC, July 2003
RJW, DMW

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on turbine efficiency, gross head, and power output.
5. Turbine prototype efficiency at 1% below the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1962 Model Test cavitation limits with a 7.0 foot safety margin.
8. The tailwater is based on the CROHMS data between 1993-1998. The turbine operating limit is based on this minimum TW with a 7.0 foot SM.
9. The generator limit is based on 115% of generator nameplate. Nameplate is142.105 MVA @ 0.95 pf = 135.0 MW.

With Fish Screens

### Table A - 20. One percent table for Lower Monumental Units 1 to 3 with STS installed

🟩 Maximum Power Output @ 1% 🟨 TW = -GH + 537.55 Gross Head to Tailwater Based on CROHMS

## Lower Monumental, Units 1-3, 1% Table with STS Installed

Based on the 1962 Model Test and 2002 Unit 2 STS Index Test with STS adjustment Factor

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (ft) | (mW) |
| 80 | **54.4** | 10,248 | **86.7%** | **62.2** | 10,817 | **93.5** | 16,076 | **114.4** | 19,891 | 129.9 | 23,815 | 449.00 | 155.3 |
| 81 | 54.8 | 10,194 | 86.8% | 63.5 | 10,892 | 95.7 | 16,233 | 117.2 | 20,106 | 132.1 | 23,924 | 449.00 | 155.3 |
| 82 | 55.2 | 10,142 | 86.9% | 64.8 | 10,964 | 97.9 | 16,386 | 120.0 | 20,314 | 134.3 | 24,031 | 449.00 | 155.3 |
| 83 | 55.6 | 10,091 | 87.0% | 66.1 | 11,035 | 100.1 | 16,534 | 122.8 | 20,517 | 136.5 | 24,137 | 449.00 | 155.3 |
| 84 | 56.0 | 10,042 | 87.1% | 67.3 | 11,103 | 102.3 | 16,678 | 125.6 | 20,714 | 138.7 | 24,241 | 449.00 | 155.3 |
| 85 | **56.4** | 9,993 | **87.2%** | **68.6** | 11,169 | **104.5** | 16,817 | **128.5** | 20,905 | 140.9 | 24,344 | 449.00 | 155.3 |
| 86 | 56.9 | 9,974 | 87.2% | 69.4 | 11,154 | 106.4 | 16,902 | 131.0 | 21,056 | 142.8 | 24,273 | 449.00 | 155.3 |
| 87 | 57.5 | 9,954 | 87.3% | 70.2 | 11,140 | 108.2 | 16,984 | 133.5 | 21,204 | 144.6 | 24,200 | 449.00 | 155.3 |
| 88 | 58.0 | 9,935 | 87.3% | 70.9 | 11,125 | 110.0 | 17,064 | 136.1 | 21,348 | 146.5 | 24,126 | 449.00 | 155.3 |
| 89 | 58.6 | 9,917 | 87.4% | 71.7 | 11,111 | 111.9 | 17,141 | 138.6 | 21,488 | 148.3 | 24,050 | 448.55 | 155.3 |
| 90 | **59.1** | 9,899 | **87.5%** | **72.4** | 11,097 | **113.7** | 17,217 | **141.2** | 21,625 | 150.2 | 23,974 | 447.55 | 155.3 |
| 91 | 59.6 | 9,863 | 87.6% | 73.3 | 11,088 | 114.3 | 17,091 | 141.6 | 21,418 | 151.5 | 23,815 | 446.55 | 155.3 |
| 92 | 60.0 | 9,828 | 87.7% | 74.1 | 11,079 | 114.8 | 16,968 | 142.0 | 21,216 | 152.8 | 23,654 | 445.55 | 155.3 |
| 93 | 60.4 | 9,794 | 87.8% | 75.0 | 11,071 | 115.4 | 16,847 | 142.4 | 21,018 | 154.0 | 23,492 | 444.55 | 155.3 |
| 94 | 60.9 | 9,760 | 87.9% | 75.8 | 11,061 | 116.0 | 16,729 | 142.8 | 20,824 | 155.2 | 23,420 | 443.55 | 155.3 |
| 95 | **61.3** | 9,727 | **88.1%** | **76.7** | 11,052 | **116.6** | 16,612 | **143.2** | 20,634 | 155.2 | 22,904 | 442.55 | 155.3 |
| 96 | 61.9 | 9,719 | 88.2% | 77.7 | 11,071 | 117.1 | 16,491 | 143.3 | 20,416 | 155.2 | 22,592 | 441.55 | 155.3 |
| 97 | 62.5 | 9,712 | 88.3% | 78.8 | 11,088 | 117.6 | 16,371 | 143.5 | 20,203 | 155.2 | 22,286 | 440.55 | 155.3 |
| 98 | 63.1 | 9,705 | 88.4% | 79.8 | 11,105 | 118.1 | 16,254 | 143.6 | 19,994 | 155.2 | 21,988 | 439.55 | 155.3 |
| 99 | 63.7 | 9,698 | 88.5% | 80.8 | 11,121 | 118.6 | 16,140 | 143.8 | 19,789 | 155.2 | 21,696 | 438.55 | 155.3 |
| 100 | **64.3** | 9,691 | **88.6%** | **81.8** | 11,137 | **119.1** | 16,027 | **144.0** | 19,589 | 155.2 | 21,410 | 437.55 | 155.3 |
| 101 | 64.9 | 9,682 | 88.7% | 82.7 | 11,138 | 120.6 | 16,059 | 145.9 | 19,641 | 155.2 | 21,130 | 436.55 | 155.3 |
| 102 | 65.5 | 9,673 | 88.7% | 83.6 | 11,140 | 122.1 | 16,089 | 147.8 | 19,692 | 155.2 | 20,857 | 436.00 | 155.3 |
| 103 | 66.1 | 9,664 | 88.8% | 84.5 | 11,141 | 123.6 | 16,119 | 149.7 | 19,741 | 155.2 | 20,589 | 436.00 | 155.3 |
| 104 | 66.6 | 9,655 | 88.8% | 85.4 | 11,142 | 125.1 | 16,149 | 151.6 | 19,789 | 155.2 | 20,326 | 436.00 | 155.3 |
| 105 | **67.2** | 9,647 | **88.9%** | **86.2** | 11,143 | **126.6** | 16,177 | **153.5** | 19,837 | 155.2 | 20,069 | 436.00 | 155.3 |
| 106 | 67.8 | 9,645 | 88.9% | 86.9 | 11,122 | 127.7 | 16,160 | 154.9 | 19,822 | 155.2 | 19,848 | 436.00 | 155.3 |
| 107 | 68.5 | 9,644 | 89.0% | 87.6 | 11,101 | 128.9 | 16,143 | 156.4 | 19,807 | 155.2 | 19,632 | 436.00 | 155.3 |
| 108 | 69.1 | 9,642 | 89.0% | 88.4 | 11,081 | 130.0 | 16,126 | 157.8 | 19,792 | 155.2 | 19,420 | 436.00 | 155.3 |
| 109 | 69.7 | 9,641 | 89.1% | 89.1 | 11,061 | 131.2 | 16,110 | 159.2 | 19,777 | 155.2 | 19,211 | 436.00 | 155.3 |
| 110 | **70.4** | 9,639 | **89.1%** | **89.8** | 11,041 | **132.3** | 16,093 | **160.7** | 19,762 | 155.2 | 19,007 | 436.00 | 155.3 |

Prepared by HDC, July 2003
RJW, DMW

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on turbine efficiency, gross head, and power output.
5. Turbine prototype efficiency at 1% below the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1962 Model Test cavitation limits with a 7.0 foot safety margin.
8. The tailwater is based on the CROHMS data between 1993-1998. The turbine operating limit is based on this minimum TW with a 7.0 foot SM.
9. The generator limit is based on 115% of generator nameplate. Nameplate is 142.105 MVA @ 0.95 pf = 135.0 MW.

### A.4.4.8 Lower Monumental Units 4 to 6

Without Screens

Table A - 21. One percent table for Lower Monumental Units 4 to 6 with no screens installed

🟩 Maximum Power Output @ 1% 🟨 TW = -GH + 537.55 Gross Head to Tailwater Based on CROHMS

## Lower Monumental, Units 4-6, 1% Table with No Screens Installed

Based on the 1975 Model Test and 2002 Unit 6 NS Index Test

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (ft) | (mW) |
| 80 | **63.3** | 11,928 | **90.5%** | **84.0** | 13,999 | **93.6** | 15,419 | **113.9** | 18,975 | 131.9 | 25,151 | 449.00 | 155.3 |
| 81 | 64.1 | 11,919 | 90.6% | 85.1 | 13,992 | 94.9 | 15,423 | 115.6 | 19,002 | 133.8 | 25,009 | 449.00 | 155.3 |
| 82 | 64.8 | 11,911 | 90.7% | 86.2 | 13,985 | 96.2 | 15,427 | 117.3 | 19,029 | 135.7 | 24,867 | 449.00 | 155.3 |
| 83 | 65.6 | 11,902 | 90.8% | 87.3 | 13,977 | 97.5 | 15,430 | 119.1 | 19,054 | 137.5 | 24,725 | 449.00 | 155.3 |
| 84 | 66.3 | 11,894 | 90.9% | 88.4 | 13,969 | 98.8 | 15,432 | 120.8 | 19,079 | 139.4 | 24,583 | 449.00 | 155.3 |
| 85 | **67.0** | 11,887 | **91.0%** | **89.5** | 13,962 | **100.1** | 15,435 | **122.5** | 19,102 | 141.3 | 24,441 | 449.00 | 155.3 |
| 86 | 67.8 | 11,879 | 91.0% | 90.7 | 13,971 | 101.4 | 15,450 | 124.2 | 19,128 | 143.3 | 24,414 | 449.00 | 155.3 |
| 87 | 68.5 | 11,871 | 91.1% | 91.9 | 13,981 | 102.8 | 15,464 | 125.9 | 19,153 | 145.4 | 24,385 | 449.00 | 155.3 |
| 88 | 69.3 | 11,864 | 91.1% | 93.1 | 13,990 | 104.1 | 15,478 | 127.6 | 19,177 | 147.4 | 24,356 | 449.00 | 155.3 |
| 89 | 70.0 | 11,857 | 91.2% | 94.2 | 13,998 | 105.4 | 15,491 | 129.3 | 19,201 | 149.4 | 24,324 | 448.55 | 155.3 |
| 90 | **70.8** | 11,850 | **91.3%** | **95.4** | 14,006 | **106.8** | 15,504 | **131.0** | 19,224 | 151.4 | 24,291 | 447.55 | 155.3 |
| 91 | 71.4 | 11,818 | 91.3% | 96.5 | 14,007 | 108.0 | 15,504 | 132.5 | 19,221 | 153.5 | 24,230 | 446.55 | 155.3 |
| 92 | 72.0 | 11,787 | 91.4% | 97.7 | 14,008 | 109.3 | 15,504 | 134.0 | 19,218 | 155.2 | 24,168 | 445.55 | 155.3 |
| 93 | 72.6 | 11,757 | 91.4% | 98.8 | 14,009 | 110.5 | 15,503 | 135.5 | 19,215 | 155.2 | 23,577 | 444.55 | 155.3 |
| 94 | 73.2 | 11,728 | 91.5% | 99.9 | 14,010 | 111.8 | 15,503 | 137.1 | 19,211 | 155.2 | 23,008 | 443.55 | 155.3 |
| 95 | **73.8** | 11,699 | **91.6%** | **101.1** | 14,010 | **113.1** | 15,502 | **138.6** | 19,208 | 155.2 | 22,460 | 442.55 | 155.3 |
| 96 | 74.3 | 11,671 | 91.6% | 102.0 | 13,982 | 113.8 | 15,439 | 139.1 | 19,067 | 155.2 | 21,828 | 441.55 | 155.3 |
| 97 | 74.9 | 11,643 | 91.6% | 102.9 | 13,954 | 114.6 | 15,377 | 139.6 | 18,929 | 155.2 | 21,478 | 440.55 | 155.3 |
| 98 | 75.5 | 11,616 | 91.7% | 103.8 | 13,928 | 115.4 | 15,316 | 140.1 | 18,794 | 155.2 | 21,136 | 439.55 | 155.3 |
| 99 | 76.1 | 11,589 | 91.7% | 104.7 | 13,901 | 116.2 | 15,256 | 140.5 | 18,662 | 155.2 | 20,803 | 438.55 | 155.3 |
| 100 | **76.7** | 11,563 | **91.8%** | **105.6** | 13,875 | **116.9** | 15,198 | **141.0** | 18,532 | 155.2 | 20,723 | 437.55 | 155.3 |
| 101 | 77.5 | 11,560 | 91.8% | 106.9 | 13,904 | 118.2 | 15,217 | 142.5 | 18,532 | 155.2 | 20,477 | 436.55 | 155.3 |
| 102 | 78.2 | 11,556 | 91.8% | 108.2 | 13,933 | 119.6 | 15,237 | 143.9 | 18,532 | 155.2 | 20,236 | 436.00 | 155.3 |
| 103 | 79.0 | 11,553 | 91.8% | 109.4 | 13,962 | 120.9 | 15,256 | 145.3 | 18,532 | 155.2 | 19,999 | 436.00 | 155.3 |
| 104 | 79.7 | 11,550 | 91.8% | 110.7 | 13,989 | 122.2 | 15,275 | 146.7 | 18,532 | 155.2 | 19,768 | 436.00 | 155.3 |
| 105 | **80.5** | 11,547 | **91.8%** | **112.0** | 14,017 | **123.5** | 15,293 | **148.1** | 18,532 | 155.2 | 19,541 | 436.00 | 155.3 |
| 106 | 81.2 | 11,544 | 91.8% | 113.1 | 14,015 | 124.9 | 15,314 | 150.1 | 18,602 | 155.2 | 19,331 | 436.00 | 155.3 |
| 107 | 81.9 | 11,541 | 91.8% | 114.1 | 14,014 | 126.2 | 15,335 | 152.0 | 18,670 | 155.2 | 19,125 | 436.00 | 155.3 |
| 108 | 82.7 | 11,538 | 91.8% | 115.2 | 14,013 | 127.6 | 15,355 | 154.0 | 18,738 | 155.2 | 18,923 | 436.00 | 155.3 |
| 109 | 83.4 | 11,535 | 91.8% | 116.2 | 14,011 | 128.9 | 15,375 | 156.0 | 18,804 | 155.2 | 18,725 | 436.00 | 155.3 |
| 110 | **84.2** | 11,532 | **91.8%** | **117.3** | 14,010 | **130.3** | 15,395 | **158.0** | 18,869 | 155.2 | 18,531 | 436.00 | 155.3 |

Prepared by HDC, July 2003
RJW, DMW

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on turbine efficiency, gross head, and power output.
5. Turbine prototype efficiency at 1% below the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1975 Model Test cavitation limits with a 7.0 foot safety margin.
8. The tailwater is based on the CROHMS data between 1993-1998. The turbine operating limit is based on this minimum TW with a 7.0 foot SM.
9. The generator limit is based on 115% of generator nameplate. Nameplate is142.105 MVA @ 0.95 pf = 135.0 MW.

With Fish Screens

**Table A - 22. One percent table for Lower Monumental Units 4 to 6 with STS installed**

🟩 Maximum Power Output @ 1%

🟨 TW = -GH + 537.55 Gross Head to Tailwater Based on CROHMS

# Lower Monumental, Units 4-6, 1% Table with STS Installed

## Based on the 1975 Model Test and 2002 Unit 6 STS Index Test with STS adjustment Factor

| [1]Gross Head | [2]Lower Limit @80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [7]Turbine Suggested Operating Limit | Turbine Discharge @Limit | [8]CROHMS Minimum Tailwater | [9]Gen. Limit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (ft) | (mW) |
| 80 | **63.9** | 12,041 | **89.6%** | **84.3** | 14,189 | **90.5** | 15,056 | **115.1** | 19,364 | 131.9 | 26,143 | 449.00 | 155.3 |
| 81 | 64.7 | 12,033 | 89.7% | 85.4 | 14,181 | 91.7 | 15,055 | 116.8 | 19,392 | 133.8 | 25,921 | 449.00 | 155.3 |
| 82 | 65.4 | 12,024 | 89.8% | 86.5 | 14,174 | 92.9 | 15,055 | 118.5 | 19,419 | 135.7 | 25,700 | 449.00 | 155.3 |
| 83 | 66.2 | 12,016 | 89.9% | 87.6 | 14,166 | 94.2 | 15,054 | 120.3 | 19,445 | 137.5 | 25,482 | 449.00 | 155.3 |
| 84 | 66.9 | 12,008 | 90.0% | 88.7 | 14,158 | 95.4 | 15,053 | 122.0 | 19,469 | 139.4 | 25,266 | 449.00 | 155.3 |
| 85 | **67.7** | 12,000 | **90.1%** | **89.8** | 14,150 | **96.6** | 15,051 | **123.8** | 19,493 | 141.3 | 25,052 | 449.00 | 155.3 |
| 86 | 68.4 | 11,992 | 90.1% | 91.0 | 14,160 | 97.9 | 15,065 | 125.5 | 19,519 | 143.3 | 24,978 | 449.00 | 155.3 |
| 87 | 69.2 | 11,984 | 90.2% | 92.2 | 14,169 | 99.2 | 15,077 | 127.2 | 19,545 | 145.4 | 24,904 | 449.00 | 155.3 |
| 88 | 69.9 | 11,977 | 90.2% | 93.4 | 14,178 | 100.5 | 15,089 | 128.9 | 19,569 | 147.4 | 24,829 | 449.00 | 155.3 |
| 89 | 70.7 | 11,970 | 90.3% | 94.6 | 14,187 | 101.8 | 15,101 | 130.6 | 19,593 | 149.4 | 24,753 | 448.55 | 155.3 |
| 90 | **71.4** | 11,963 | **90.4%** | **95.7** | 14,195 | **103.1** | 15,112 | **132.3** | 19,616 | 151.4 | 24,676 | 447.55 | 155.3 |
| 91 | 72.0 | 11,931 | 90.4% | 96.9 | 14,196 | 104.3 | 15,112 | 133.9 | 19,613 | 153.5 | 24,623 | 446.55 | 155.3 |
| 92 | 72.7 | 11,900 | 90.5% | 98.0 | 14,197 | 105.5 | 15,112 | 135.4 | 19,610 | 155.2 | 24,553 | 445.55 | 155.3 |
| 93 | 73.3 | 11,869 | 90.5% | 99.2 | 14,197 | 106.7 | 15,112 | 136.9 | 19,607 | 155.2 | 23,936 | 444.55 | 155.3 |
| 94 | 73.9 | 11,839 | 90.6% | 100.3 | 14,198 | 107.9 | 15,112 | 138.5 | 19,603 | 155.2 | 23,343 | 443.55 | 155.3 |
| 95 | **74.5** | 11,810 | **90.7%** | **101.4** | 14,198 | **109.1** | 15,111 | **140.0** | 19,600 | 155.2 | 22,771 | 442.55 | 155.3 |
| 96 | 75.1 | 11,782 | 90.7% | 102.3 | 14,170 | 110.0 | 15,061 | 140.5 | 19,456 | 155.2 | 22,389 | 441.55 | 155.3 |
| 97 | 75.7 | 11,754 | 90.7% | 103.2 | 14,142 | 110.8 | 15,011 | 141.0 | 19,315 | 155.2 | 22,017 | 440.55 | 155.3 |
| 98 | 76.3 | 11,726 | 90.8% | 104.1 | 14,114 | 111.6 | 14,962 | 141.5 | 19,177 | 155.2 | 21,654 | 439.55 | 155.3 |
| 99 | 76.9 | 11,699 | 90.8% | 105.1 | 14,087 | 112.4 | 14,914 | 142.0 | 19,042 | 155.2 | 21,300 | 438.55 | 155.3 |
| 100 | **77.5** | 11,673 | **90.9%** | **106.0** | 14,061 | **113.3** | 14,867 | **142.5** | 18,909 | 155.2 | 20,955 | 437.55 | 155.3 |
| 101 | 78.2 | 11,670 | 90.9% | 107.3 | 14,091 | 114.6 | 14,891 | 143.9 | 18,909 | 155.2 | 20,701 | 436.55 | 155.3 |
| 102 | 79.0 | 11,666 | 90.9% | 108.5 | 14,120 | 115.9 | 14,914 | 145.4 | 18,909 | 155.2 | 20,452 | 436.00 | 155.3 |
| 103 | 79.7 | 11,663 | 90.9% | 109.8 | 14,149 | 117.2 | 14,936 | 146.8 | 18,909 | 155.2 | 20,208 | 436.00 | 155.3 |
| 104 | 80.5 | 11,660 | 90.9% | 111.1 | 14,177 | 118.5 | 14,959 | 148.2 | 18,909 | 155.2 | 19,970 | 436.00 | 155.3 |
| 105 | **81.2** | 11,657 | **90.9%** | **112.4** | 14,204 | **119.8** | 14,980 | **149.6** | 18,909 | 155.2 | 19,736 | 436.00 | 155.3 |
| 106 | 82.0 | 11,654 | 90.9% | 113.5 | 14,203 | 121.1 | 14,994 | 151.6 | 18,981 | 155.2 | 19,519 | 436.00 | 155.3 |
| 107 | 82.7 | 11,651 | 90.9% | 114.5 | 14,202 | 122.3 | 15,006 | 153.6 | 19,051 | 155.2 | 19,307 | 436.00 | 155.3 |
| 108 | 83.5 | 11,648 | 90.9% | 115.6 | 14,200 | 123.6 | 15,019 | 155.6 | 19,120 | 155.2 | 19,099 | 436.00 | 155.3 |
| 109 | 84.2 | 11,645 | 90.9% | 116.6 | 14,199 | 124.8 | 15,031 | 157.6 | 19,187 | 155.2 | 18,894 | 436.00 | 155.3 |
| 110 | **85.0** | 11,642 | **90.9%** | **117.7** | 14,198 | **126.1** | 15,043 | **159.6** | 19,253 | 155.2 | 18,694 | 436.00 | 155.3 |

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 98% turbine power in this table.
4. Discharge in this table is a calculated number based on turbine efficiency, gross head, and power output.
5. Turbine prototype efficiency at 1% below the best operating point.
6. The best operating point of the turbine at each head.
7. The turbine suggested limit (given as generator output) is based on the 1975 Model Test cavitation limits with a 7.0 foot safety margin.
8. The tailwater is based on the CROHMS data between 1993-1998. The turbine operating limit is based on this minimum TW with a 7.0 foot SM.
9. The generator limit is based on 115% of generator nameplate. Nameplate is142.105 MVA @ 0.95 pf = 135.0 MW.

Prepared by HDC, July 2003
RJW, DMW

### A.4.4.9 Lower Granite Units 4 to 6

#### Without Screens

**Table A - 23. One percent table for Lower Granite Units 4 to 6 with no screens installed**

## Lower Granite, U4-6, 1% Table with No Screens Installed

Based on the 1995 Index test and the 1975 Model Test

| [1]Gross Head | [2]Lower Limit @ 80.0% Turbine Effic. | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [8]Turbine Operating Limit | [9]CROHMS Minimum Tailwater | [7]Gen. Limit 115% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (fmsl) | (mW) |
| 75 | **56.5** | 11,235 | **86.8%** | **73.2** | 13,418 | **75.2** | 13,634 | **86.4** | 15,839 | 120.9 | 657.38 | 163.4 |
| 76 | 57.2 | 11,221 | 87.0% | 74.3 | 13,419 | 76.6 | 13,677 | 88.0 | 15,880 | 122.8 | 656.42 | 163.4 |
| 77 | 57.8 | 11,207 | 87.2% | 75.5 | 13,419 | 78.0 | 13,718 | 89.5 | 15,918 | 124.7 | 655.47 | 163.4 |
| 78 | 58.5 | 11,194 | 87.3% | 76.6 | 13,419 | 79.4 | 13,757 | 91.1 | 15,954 | 126.6 | 654.52 | 163.4 |
| 79 | 59.2 | 11,181 | 87.5% | 77.7 | 13,418 | 80.8 | 13,795 | 92.6 | 15,989 | 128.5 | 653.57 | 163.4 |
| 80 | **59.9** | 11,168 | **87.7%** | **78.9** | 13,416 | **82.2** | 13,830 | **94.2** | 16,021 | 130.3 | 652.62 | 163.4 |
| 81 | 60.4 | 11,130 | 87.8% | 80.1 | 13,442 | 83.3 | 13,812 | 98.0 | 16,434 | 132.4 | 651.67 | 163.4 |
| 82 | 61.0 | 11,094 | 87.9% | 81.4 | 13,466 | 84.3 | 13,794 | 101.7 | 16,835 | 134.4 | 650.72 | 163.4 |
| 83 | 61.5 | 11,058 | 88.1% | 82.6 | 13,489 | 85.3 | 13,776 | 105.5 | 17,225 | 136.4 | 649.76 | 163.4 |
| 84 | 62.1 | 11,023 | 88.2% | 83.9 | 13,511 | 86.4 | 13,758 | 109.3 | 17,604 | 138.4 | 648.81 | 163.4 |
| 85 | **62.6** | 10,989 | **88.3%** | **85.1** | 13,532 | **87.4** | 13,740 | **113.0** | 17,972 | 140.4 | 647.86 | 163.4 |
| 86 | 63.4 | 10,991 | 88.4% | 86.1 | 13,515 | 88.9 | 13,798 | 114.6 | 17,988 | 142.5 | 646.91 | 163.4 |
| 87 | 64.1 | 10,993 | 88.5% | 87.1 | 13,497 | 90.4 | 13,855 | 115.6 | 17,914 | 144.6 | 645.96 | 163.4 |
| 88 | 64.9 | 10,995 | 88.6% | 88.1 | 13,480 | 91.9 | 13,910 | 116.6 | 17,842 | 146.7 | 645.01 | 163.4 |
| 89 | 65.6 | 10,998 | 88.7% | 89.1 | 13,463 | 93.4 | 13,963 | 117.6 | 17,771 | 148.8 | 644.06 | 163.4 |
| 90 | **66.4** | 11,000 | **88.8%** | **90.0** | 13,446 | **94.9** | 14,015 | **120.8** | 18,045 | 150.8 | 643.10 | 163.4 |
| 91 | 67.1 | 10,995 | 88.8% | 91.2 | 13,465 | 96.1 | 14,025 | 122.6 | 18,102 | 152.9 | 642.15 | 163.4 |
| 92 | 67.8 | 10,990 | 88.9% | 92.4 | 13,483 | 97.3 | 14,035 | 124.4 | 18,158 | 155.0 | 641.20 | 163.4 |
| 93 | 68.5 | 10,985 | 88.9% | 93.6 | 13,501 | 98.4 | 14,045 | 126.2 | 18,212 | 157.1 | 640.25 | 163.4 |
| 94 | 69.2 | 10,980 | 89.0% | 94.7 | 13,519 | 99.6 | 14,054 | 128.0 | 18,265 | 159.2 | 639.30 | 163.4 |
| 95 | **69.9** | 10,975 | **89.0%** | **95.9** | 13,535 | **100.8** | 14,063 | **129.8** | 18,317 | 161.3 | 638.35 | 163.4 |
| 96 | 70.6 | 10,963 | 89.0% | 96.9 | 13,533 | 104.2 | 14,390 | 131.3 | 18,329 | 163.4 | 637.40 | 163.4 |
| 97 | 71.2 | 10,951 | 89.1% | 98.0 | 13,530 | 107.7 | 14,709 | 132.8 | 18,340 | 165.5 | 636.44 | 163.4 |
| 98 | 71.9 | 10,940 | 89.1% | 99.0 | 13,527 | 111.2 | 15,022 | 134.3 | 18,350 | 167.7 | 635.49 | 163.4 |
| 99 | 72.5 | 10,928 | 89.2% | 100.0 | 13,524 | 114.6 | 15,328 | 135.8 | 18,360 | 169.8 | 634.54 | 163.4 |
| 100 | **73.2** | 10,917 | **89.2%** | **101.1** | 13,521 | **118.1** | 15,627 | **137.3** | 18,370 | 171.9 | 633.59 | 163.4 |
| 101 | 73.9 | 10,913 | 89.3% | 102.3 | 13,539 | 119.6 | 15,659 | 138.0 | 18,268 | 172.8 | 632.64 | 163.4 |
| 102 | 74.6 | 10,908 | 89.3% | 103.5 | 13,557 | 121.1 | 15,690 | 138.7 | 18,167 | 173.7 | 631.69 | 163.4 |
| 103 | 75.3 | 10,904 | 89.4% | 104.7 | 13,574 | 122.6 | 15,720 | 139.4 | 18,068 | 174.6 | 630.74 | 163.4 |
| 104 | 76.0 | 10,899 | 89.4% | 105.9 | 13,590 | 124.1 | 15,749 | 140.1 | 17,971 | 175.4 | 629.78 | 163.4 |
| 105 | **76.7** | 10,895 | **89.5%** | **107.1** | 13,606 | **125.6** | 15,778 | **140.8** | 17,876 | 176.1 | 628.83 | 163.4 |

Prepared March 1999
by HDC (RJW, DMW)

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 99% turbine power in this table.
4. Discharge in this table is a calculated number based on model efficiency, gross head, and power output.
5. Turbine model efficiency at a 1% drop from the best operating point.
6. The best operating point of the turbine at each head.
7. The generator limit is based on 115% of generator nameplate.
8. The turbine maximum limit is based on the 1975 model cavitation tests with a 10' SM (safety margin).
9. The minimum tailwater is based on the CROHMS data between 1990-1997. The turbine operating limit is based on this min TW with a 10' SM.

With Fish Screens:

**Table A - 24. One percent table for Lower Granite Units 4 to 6 with ESBS installed**

# Lower Granite, U4-6, 1% Table with ESBS Installed

## Based on the 1995 IndexTest and the 1975 Model Test with the ESBS Adjustment Factors

| [1]Gross Head | [2]Lower Limit @ 80.0% Turbine Effic | | [5]Turbine 1% Limit Expected eff. | Lower 1% Limit | | [6]Best Turbine Operating Efficiency | | Upper 1% Limit | | [8]Turbine Operating Limit | [9]CROHMS Minimum Tailwater | [7]Gen. Limit 115% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]Generator Power | [4]Discharge | | Generator Power | Discharge | Generator Power | Discharge | Generator Power | Discharge | | | |
| (ft) | (mW) | (cfs) | (%) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (cfs) | (mW) | (fmsl) | (mW) |
| 75 | **55.3** | 11,003 | **85.1%** | **71.6** | 13,396 | **73.1** | 13,503 | **80.9** | 15,122 | 120.9 | 657.4 | 163.4 |
| 76 | 56.0 | 10,990 | 85.3% | 72.8 | 13,396 | 74.4 | 13,536 | 82.3 | 15,160 | 122.8 | 656.4 | 163.4 |
| 77 | 56.7 | 10,976 | 85.5% | 73.9 | 13,396 | 75.7 | 13,567 | 83.8 | 15,196 | 124.7 | 655.5 | 163.4 |
| 78 | 57.3 | 10,963 | 85.6% | 75.0 | 13,395 | 77.0 | 13,596 | 85.3 | 15,230 | 126.6 | 654.5 | 163.4 |
| 79 | 58.0 | 10,951 | 85.8% | 76.1 | 13,394 | 78.3 | 13,624 | 86.7 | 15,262 | 128.5 | 653.6 | 163.4 |
| 80 | **58.7** | 10,938 | **86.0%** | **77.2** | 13,392 | **79.6** | 13,650 | **88.2** | 15,293 | 130.3 | 652.6 | 163.4 |
| 81 | 59.2 | 10,901 | 86.1% | 78.4 | 13,416 | 80.7 | 13,650 | 91.7 | 15,686 | 132.4 | 651.7 | 163.4 |
| 82 | 59.7 | 10,865 | 86.2% | 79.6 | 13,440 | 81.8 | 13,650 | 95.2 | 16,069 | 134.4 | 650.7 | 163.4 |
| 83 | 60.3 | 10,830 | 86.4% | 80.9 | 13,463 | 82.9 | 13,649 | 98.7 | 16,440 | 136.4 | 649.8 | 163.4 |
| 84 | 60.8 | 10,796 | 86.5% | 82.1 | 13,485 | 84.0 | 13,648 | 102.3 | 16,801 | 138.4 | 648.8 | 163.4 |
| 85 | **61.3** | 10,763 | **86.6%** | **83.3** | 13,505 | **85.1** | 13,646 | **105.8** | 17,152 | 140.4 | 647.9 | 163.4 |
| 86 | 62.1 | 10,765 | 86.7% | 84.3 | 13,488 | 86.5 | 13,692 | 107.3 | 17,167 | 142.5 | 646.9 | 163.4 |
| 87 | 62.8 | 10,767 | 86.8% | 85.2 | 13,470 | 87.9 | 13,736 | 108.7 | 17,182 | 144.6 | 646.0 | 163.4 |
| 88 | 63.5 | 10,769 | 86.9% | 86.2 | 13,453 | 89.3 | 13,778 | 110.2 | 17,195 | 146.7 | 645.0 | 163.4 |
| 89 | 64.3 | 10,771 | 87.0% | 87.2 | 13,435 | 90.7 | 13,819 | 111.7 | 17,208 | 148.8 | 644.1 | 163.4 |
| 90 | **65.0** | 10,773 | **87.1%** | **88.1** | 13,418 | **92.1** | 13,859 | **113.1** | 17,220 | 150.8 | 643.1 | 163.4 |
| 91 | 65.7 | 10,768 | 87.1% | 89.3 | 13,437 | 93.2 | 13,872 | 114.8 | 17,274 | 152.9 | 642.2 | 163.4 |
| 92 | 66.4 | 10,763 | 87.2% | 90.4 | 13,455 | 94.4 | 13,883 | 116.5 | 17,328 | 155.0 | 641.2 | 163.4 |
| 93 | 67.1 | 10,758 | 87.2% | 91.6 | 13,473 | 95.5 | 13,895 | 118.1 | 17,379 | 157.1 | 640.2 | 163.4 |
| 94 | 67.8 | 10,754 | 87.3% | 92.7 | 13,490 | 96.7 | 13,906 | 119.8 | 17,430 | 159.2 | 639.3 | 163.4 |
| 95 | **68.5** | 10,749 | **87.3%** | **93.9** | 13,507 | **97.8** | 13,917 | **121.5** | 17,479 | 161.3 | 638.3 | 163.4 |
| 96 | 69.1 | 10,737 | 87.3% | 94.9 | 13,504 | 100.6 | 14,150 | 122.9 | 17,490 | 163.4 | 637.4 | 163.4 |
| 97 | 69.7 | 10,726 | 87.4% | 95.9 | 13,501 | 103.3 | 14,377 | 124.3 | 17,500 | 165.5 | 636.4 | 163.4 |
| 98 | 70.4 | 10,715 | 87.4% | 96.9 | 13,498 | 106.0 | 14,600 | 125.7 | 17,510 | 167.7 | 635.5 | 163.4 |
| 99 | 71.0 | 10,703 | 87.5% | 97.9 | 13,495 | 108.7 | 14,818 | 127.1 | 17,520 | 169.8 | 634.5 | 163.4 |
| 100 | **71.7** | 10,693 | **87.5%** | **98.9** | 13,492 | **111.5** | 15,032 | **128.5** | 17,529 | 171.9 | 633.6 | 163.4 |
| 101 | 72.4 | 10,688 | 87.6% | 100.1 | 13,510 | 113.1 | 15,091 | 129.2 | 17,431 | 172.8 | 632.6 | 163.4 |
| 102 | 73.1 | 10,683 | 87.6% | 101.3 | 13,527 | 114.7 | 15,149 | 129.8 | 17,335 | 173.7 | 631.7 | 163.4 |
| 103 | 73.7 | 10,679 | 87.7% | 102.5 | 13,544 | 116.4 | 15,206 | 130.5 | 17,240 | 174.6 | 630.7 | 163.4 |
| 104 | 74.4 | 10,675 | 87.7% | 103.7 | 13,560 | 118.0 | 15,261 | 131.1 | 17,147 | 175.4 | 629.8 | 163.4 |
| 105 | **75.1** | 10,670 | **87.8%** | **104.9** | 13,576 | **119.7** | 15,315 | **131.8** | 17,056 | 176.1 | 628.8 | 163.4 |

Prepared March 1999
by HDC (RJW, DMW)

1. The difference between the forebay and the tailwater elevations.
2. Historically, the minimum operating point of the turbine at 80% model efficiency.
3. Generator power is assumed to be 99% turbine power in this table.
4. Discharge in this table is a calculated number based on model efficiency, gross head, and power output.
5. Turbine model efficiency at a 1% drop from the best operating point.
6. The peak efficiency point of the turbine at each head.
7. The generator limit is based on 115% of generator nameplate.
8. The turbine maximum limit is based on the 1975 model cavitation tests with a 10' SM (safety margin).
9. The minimum tailwater is based on the CROHMS data between 1990-1997. The turbine operating limit is based on this min TW with a 10' SM.

## A.5 Surface Roughness

During preparations for biological testing and Index testing calibrations, it became apparent that the surface roughness of existing turbines had degraded. The effect of surface roughness on fish injury and mortality is unknown. It was noted during turbine model studies at ERDC that the potential appears to exist for fish impact or contact with fixed or moving turbine surfaces. It was also determined that the apparent turbine efficiency loss without fish screens installed may be partially caused by the increased roughness. The U.S. Army Corps of Engineers (USACE), in an effort to improve the efficiency of hydroelectric turbines, has investigated the relationship between increased surface roughness in turbines and historical efficiency degradation.

### A.5.1 Turbine Performance Loss

Figure A - 32 presents a summary of historical testing of Unit 9 at The Dalles. The apparent efficiency loss could not be immediately explained and an investigation of surface finish was undertaken.

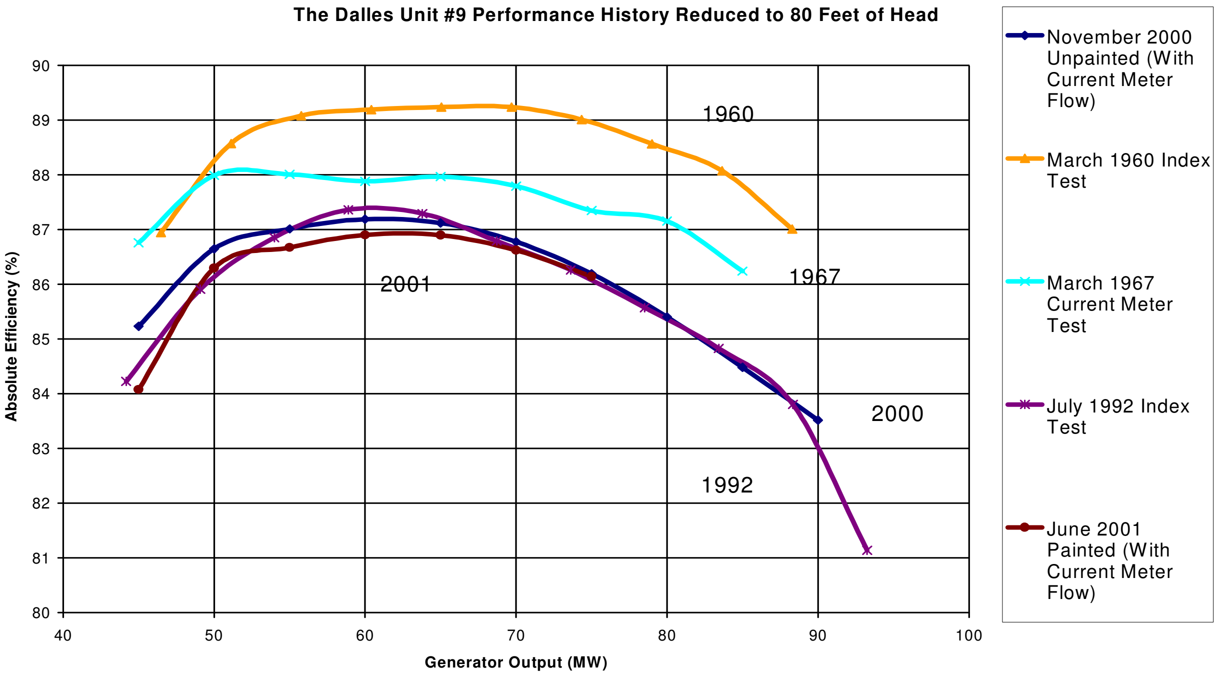


**Figure A - 32. A graph of The Dalles historical turbine performance loss**

## A.5.2 Existing Turbine Metal Surfaces

The following two figures, Figure A - 33 and Figure A - 34, show typical surfaces of existing turbines that have not been repainted since original installation.

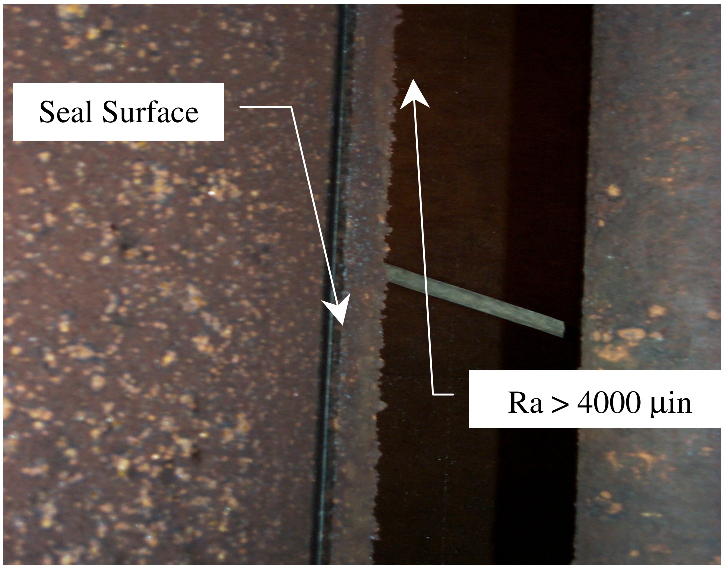


**Figure A - 33. The Dalles Unit 4 wicket gate leading edge Ra > 4000 µinches**

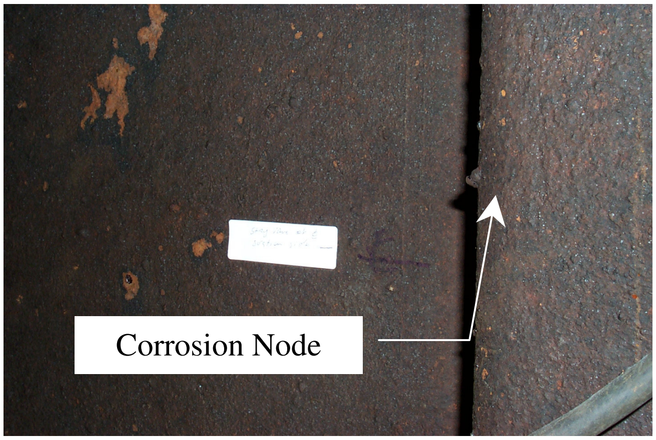


**Figure A - 34. The Dalles Unit 4 stay vane suction side Ra @ 1970 µinches**

## A.5.3 Rehabilitated (Bonneville I MGR) Painted Surfaces

As the roughness investigations progressed an inspection of a recently rehabilitated turbine at Bonneville I was performed. This investigation indicated that the standard surface preparation used for rehabilitated turbines did not achieve the levels of surface finish that were specified when the turbines were initially installed (125 to 250 µinches). Figure A - 35 and Figure A - 36 show resurfaced (sand blasted and painted) turbine components. Note the waviness of the corrosion pock-marked surface.

Figure A - 35.  Bonneville Unit 4 stay ring top and bottom Ra @ 1100 – 1180 µinches

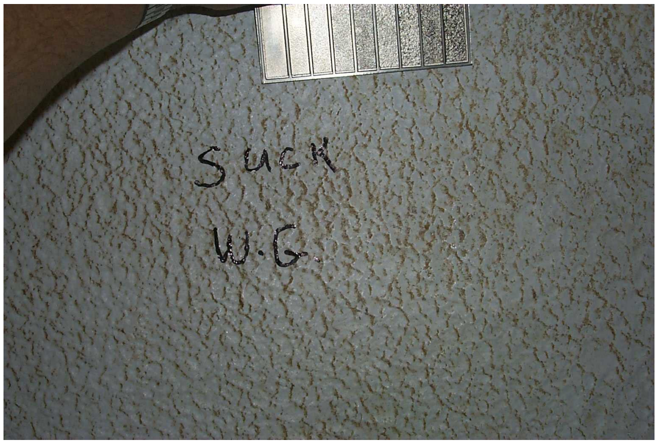


Figure A - 36.  Bonneville Unit 4 wicket gate suction side Ra @ 1050-1150 µinches

### A.5.4 Potential Future Rehabilitation Actions

Based on performance and surface preparation testing, as well as pre and post-paint inspection of hydroelectric turbines, new specifications have been produced that will decrease the surface roughness of older turbines without excess additional downtime and expense. Figure A - 37 shows a test panel on an old turbine runner blade used to establish surface finished requirements. The surface roughness specifications are as follows:

- Grinding operation: Ra ≤ 300 µinches (average) and Ry ≤ 1100 µinches (peak to valley)
- Blasting operation: Ra ≤ 425 µinches and Ry ≤ 2700 µinches with the appropriate angular tooth pattern
- Final paint surface roughness of Ra ≤ 250 µinches and Ry ≤ 500 µinches

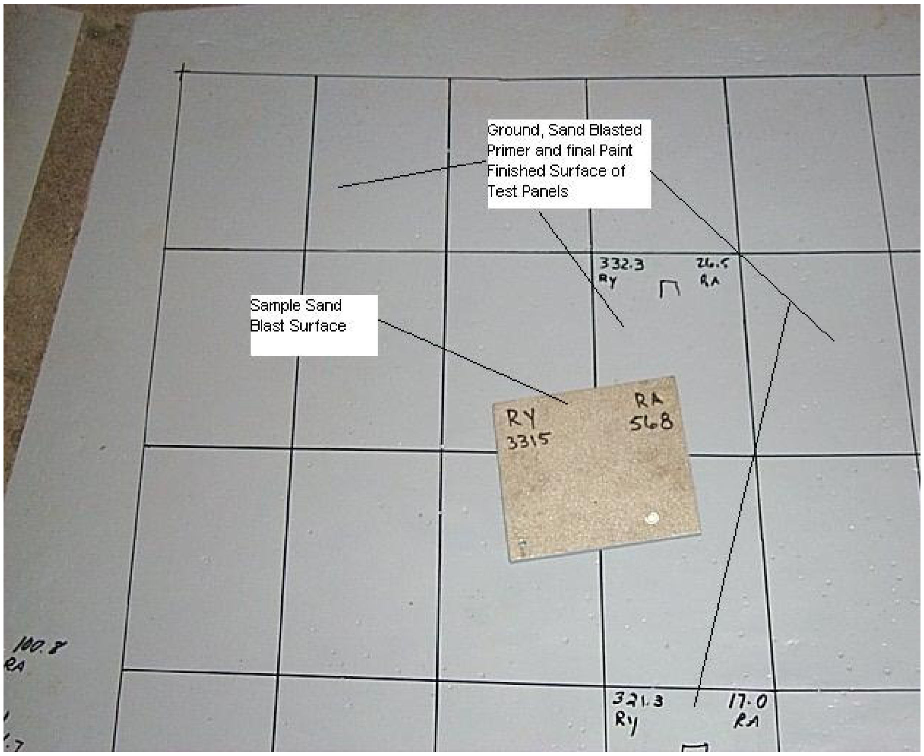


Figure A - 37. Example surface finish test panel on old turbine runner blade

## A.6 Stop Log Slot Closure

A recent study of fish survival through turbines at Bonneville First Powerhouse revealed juvenile salmon are potentially negatively impacted by stop log slots that are not open to the tailrace (Normandeau and Associates, 2000). To address this problem, it is proposed that the tailrace stop log slots at BI, and McNary Powerhouse be fitted with streamlining devices that serve to prevent juvenile salmon from entering the slots and becoming entrapped. Information gathered under Turbine Survival Program (TSP) turbine model testing indicates that this modification may also improve efficiency of the units and so a coincident economic benefit may be realized. The potential benefit of streamlining devices on both fish survival and turbine efficiency are summarized below.

### A.6.1 Draft Tube Stop Log Slots

Two basic types of stop log slot designs are used at Columbia and Snake River dams. The first design is closed to the tailrace and hence allows no escape route for fish attempting to escape upwards through the stop log slot. The second design is open to the tailrace, allowing fish to escape through the top of the stop log slot. Figure A - 38 and Figure A - 39 illustrate the two different designs.

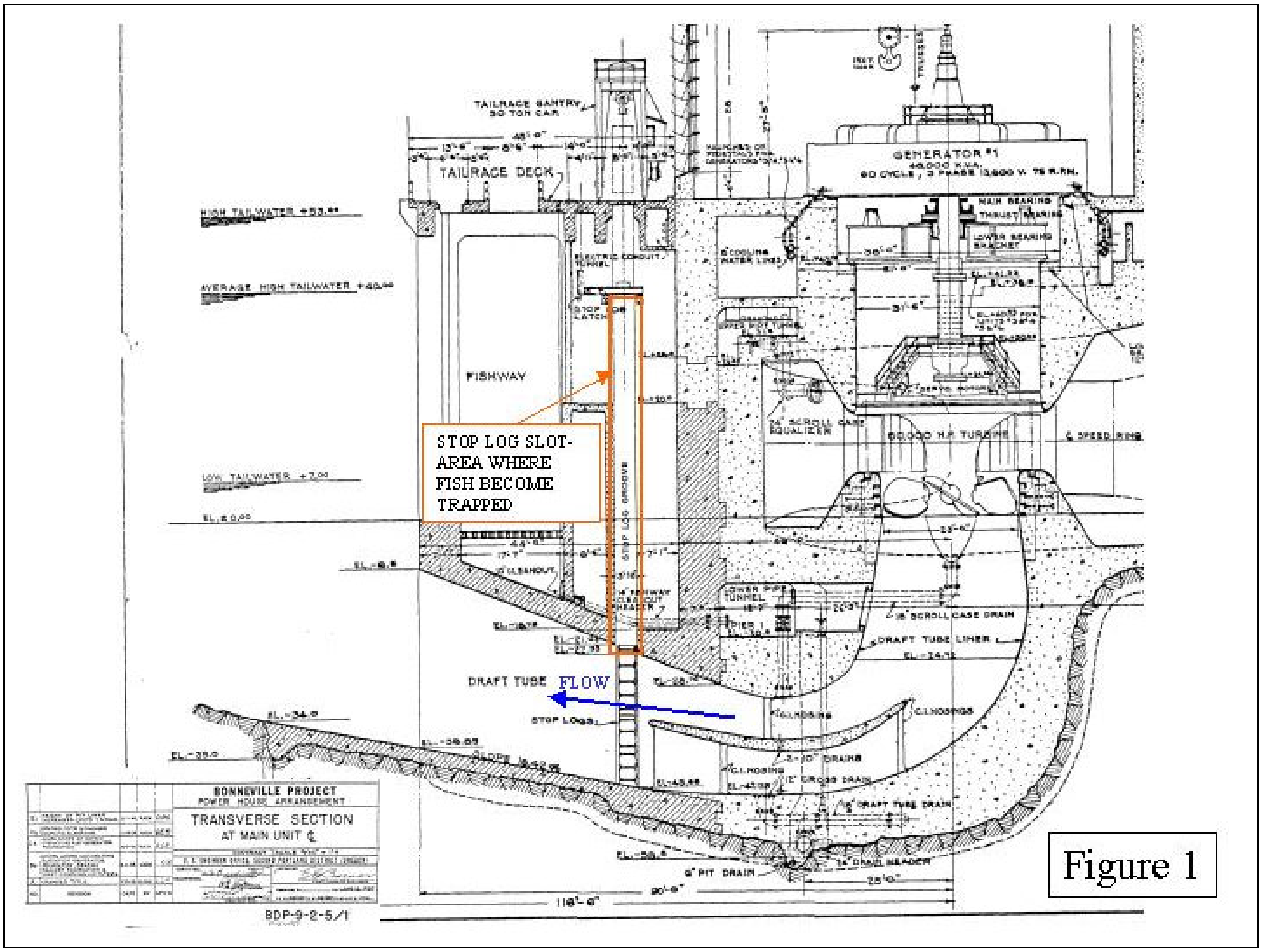


Figure A - 38. In Design #1, the stop log slot is closed to the tailrace

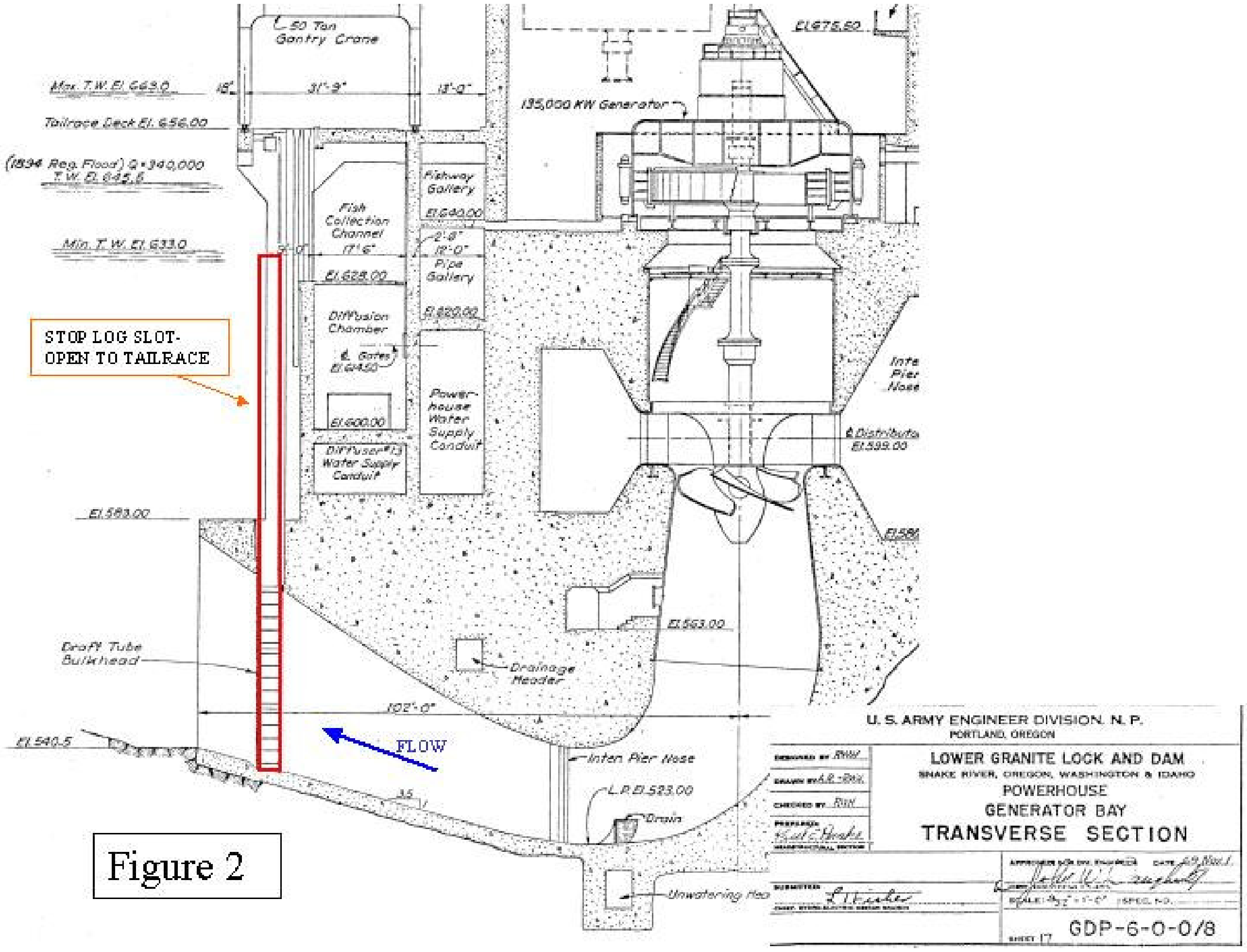


Figure 2

Figure A - 39. In Design #2, the stop log slot is open to the tailrace

## A.6.2 Possible Performance Improvement

Model testing on the Lower Granite turbine performance model indicated that closure of the stop log slots had a positive influence on the turbine performance. This improvement is on the order of a few tenths of a percent in efficiency improvement. This improvement is on the stop log slots open to tailwater. It should be noted that the original design configuration for The Dalles turbines included a closure device for the slot. The turbine efficiency improvement in the closed draft-tube stop log slot based on preliminary model testing information indicates improvements approaching 0.5 percent or more could be expected. Shown in Figure A - 40 is the model test data from a simplified closure test and Figure A - 41 shows the simplified closure without any stream lining.

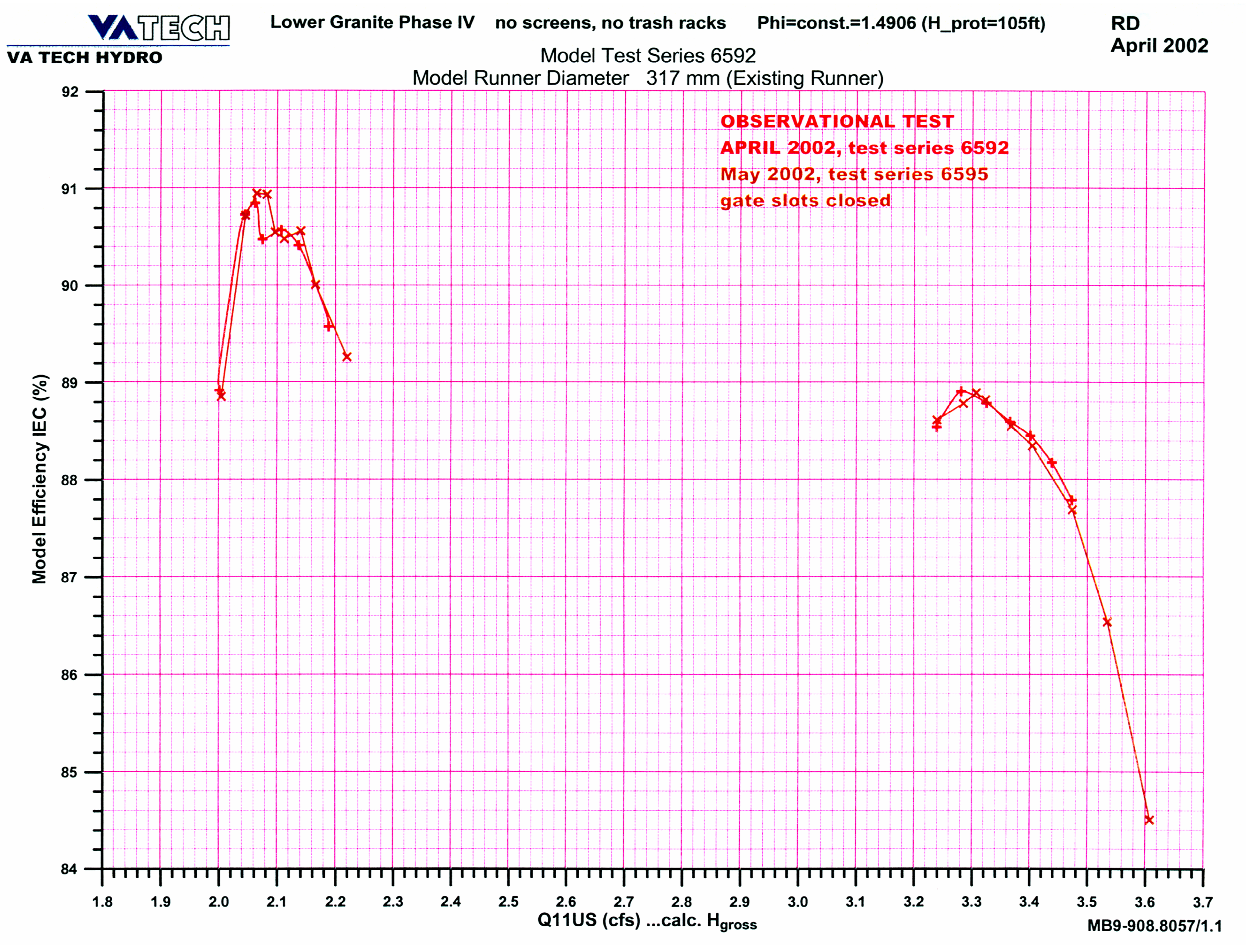


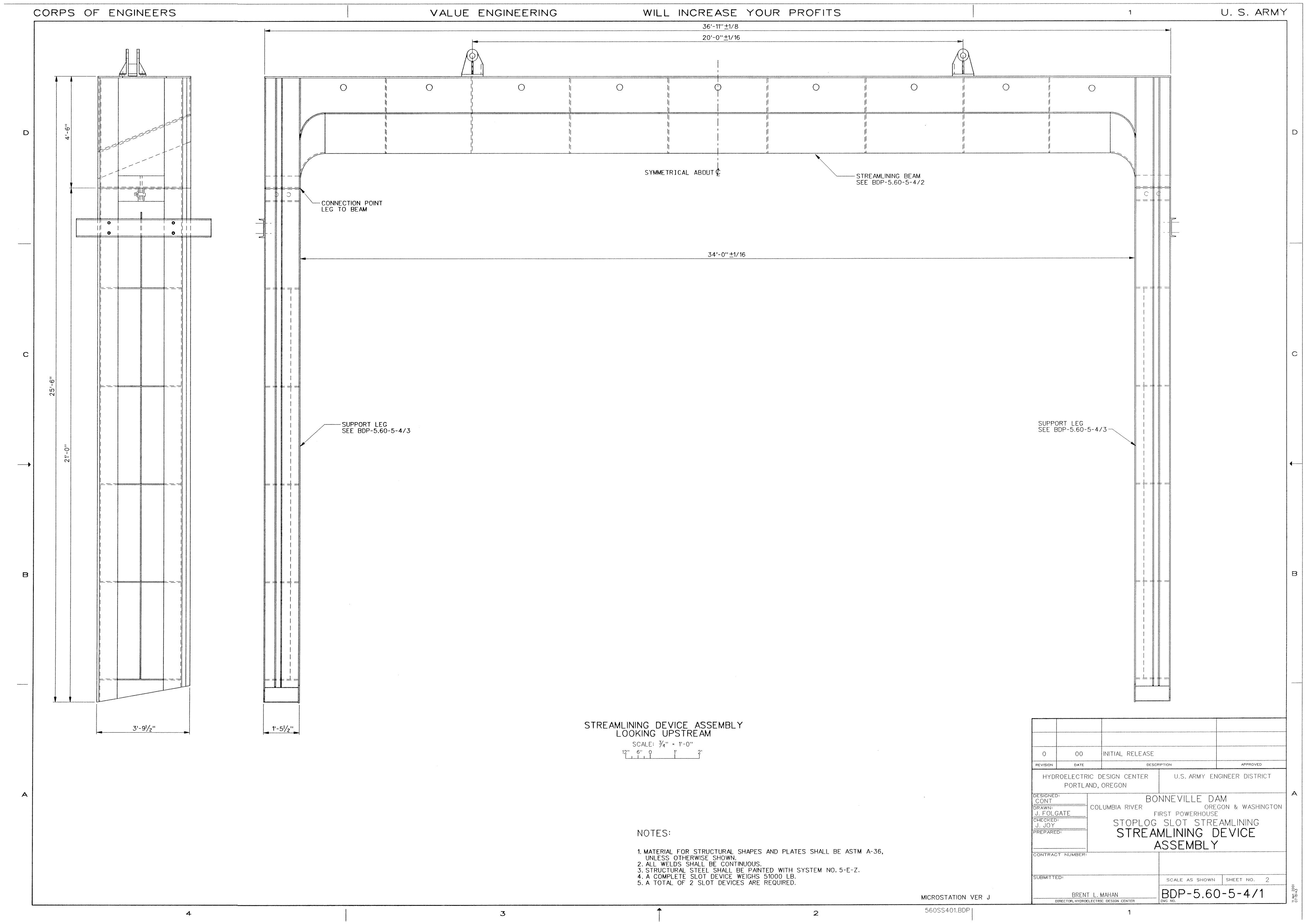
Figure A - 40. Model test results showing improved turbine performance with simplified closure

**Figure A - 41. View of simplified stop log closure in a Snake River model**

### A.6.3 Streamlining Device

Figure A - 42 shows a drawing of the recommended stop log streamlining device. The following recommendations result from investigation of potential biological and economic benefit resulting from installation of stop log streamlining devices on Columbia and Snake River powerhouses:

1. Evaluate potential fish passage benefit at Bonneville I and McNary powerhouses.
2. Install Bonneville I proof of concept device and evaluate.
3. If Bonneville I device performs as expected, install devices on all Bonneville I units.
4. Install the McNary proof of concept design and evaluate.
5. If the McNary proof of concept device performs as expected, install devices on all McNary units.
6. Consider stop log streamlining devices for other Columbia and Snake River powerhouses after further investigation of potential biological benefits.



STREAMLINING DEVICE ASSEMBLY
LOOKING UPSTREAM
SCALE: ¾" = 1'-0"

NOTES:

1. MATERIAL FOR STRUCTURAL SHAPES AND PLATES SHALL BE ASTM A-36, UNLESS OTHERWISE SHOWN.
2. ALL WELDS SHALL BE CONTINUOUS.
3. STRUCTURAL STEEL SHALL BE PAINTED WITH SYSTEM NO. 5-E-Z.
4. A COMPLETE SLOT DEVICE WEIGHS 51000 LB.
5. A TOTAL OF 2 SLOT DEVICES ARE REQUIRED.

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HYDROELECTRIC DESIGN CENTER
PORTLAND, OREGON

U.S. ARMY ENGINEER DISTRICT

DESIGNED: CONT
DRAWN: J. FOLGATE
CHECKED: J. JOY
PREPARED:

BONNEVILLE DAM
COLUMBIA RIVER OREGON & WASHINGTON
FIRST POWERHOUSE
STOPLOG SLOT STREAMLINING
STREAMLINING DEVICE
ASSEMBLY

CONTRACT NUMBER:

SUBMITTED:
BRENT L. MAHAN
DIRECTOR, HYDROELECTRIC DESIGN CENTER

SCALE AS SHOWN
SHEET NO. 2

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Figure A - 42. Conceptual design of a recommended stop log streamlining device

## A.7 Stay Vane and Wicket Gate Alignment

The alignment of the stay vanes to wicket gates was investigated in the Lower Granite model for the McNary 2002 biological test. Figure A - 43 shows a typical relationship with the wicket gates in the full closed, lower end of one percent and upper end of one percent operating ranges. Figure A - 44 shows two of the four alternate geometries used for the McNary 2002 biological test. This biological test indicated that best hydraulic geometry appeared to provide improved biological performance over the best physical geometry. Model measurements at ERDC of closure of the gap between the stay vanes and wicket gates indicated the potential for further improvements. Performance model testing has indicated a turbine performance improvement also occurs with closure of this gap.

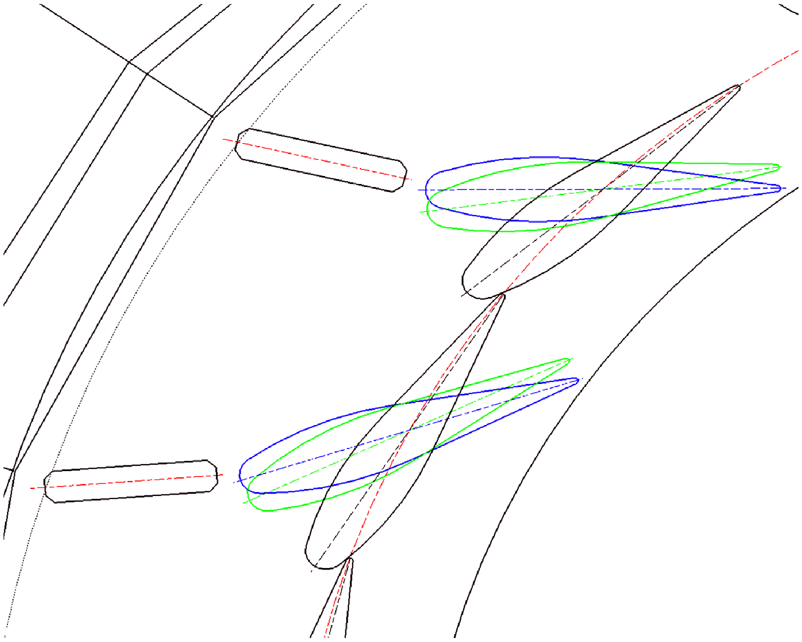

**Figure A - 43. Example stay vane – wicket gate relationship**

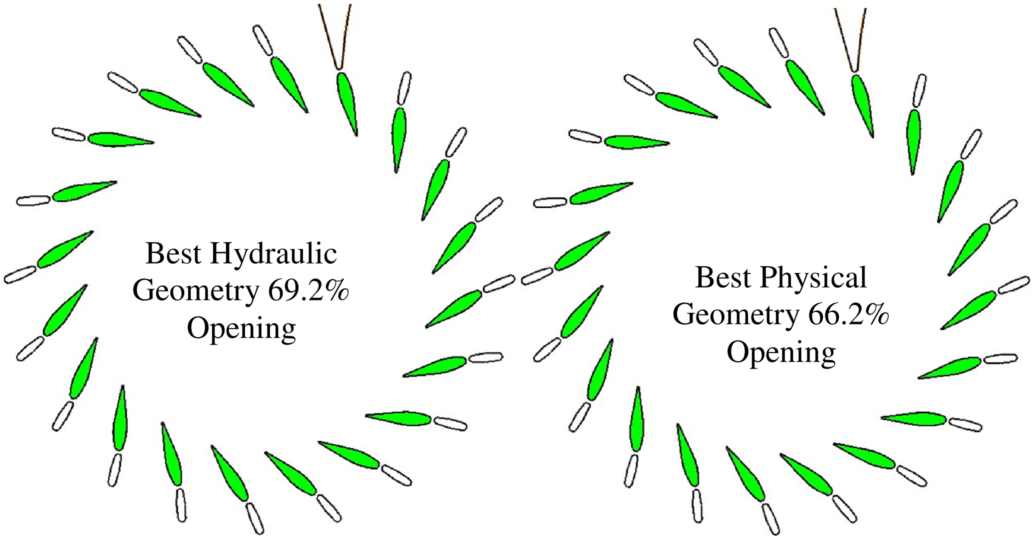

**Figure A - 44. Best hydraulic and physical geometries of the wicket gate-stay vane relationship**