Effect of a Prototype Surface Collector and Juvenile Fish Diversion Screens on Turbine Efficiency Measured at Unit 5, Bonneville Dam

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ABSTRACT

Turbine efficiency measurements were made at Unit 5, Bonneville Dam on the Columbia River in August and September of 1998. The work was done as part of a program to improve fish passage through Kaplan turbines in the Columbia River plants. In this case, the effect on turbine efficiency of a prototype surface collector (PSC), with and without juvenile fish diversion screens in place was to be assessed. The results were also intended to provide baseline information on the performance of existing turbines for comparison with the performance of new minimum gap runner units, which were being installed. Power, head and discharge were measured at a series of wicket gate settings, both on cam and off-cam for selected blade angles under three different intake configurations: with the PSC open and no screens in place; with the PSC open and screens installed; with the PSC closed and screens installed. Absolute discharges were obtained using an Acoustic Scintillation Flow Meter (ASFM) installed in the head gate slots. Relative discharge data were also collected using Winter-Kennedy taps for comparison with the absolute values from the ASFM. The effect of the differing intake configurations on the turbine efficiency is discussed.

Introduction

The Corps of Engineers has an ongoing program to improve juvenile fish passage and survival at its hydroelectric plants on the Columbia River system. Extended length Submerged Standard Bar Screens (ESBSs) or Standard length Submerged Travelling Screens (STSs) are commonly used at the Columbia system plants to divert juvenile fish away from operating turbines and into fish passage facilities. Prototype surface collectors have recently been introduced and tested as potential devices to improve fish passage and Fish Guidance Efficiency (FGE) of the diversion screens. Turbine efficiency data are an important part of the program, both for assessing the effects of diversion equipment on electricity production, and because the survival rate for fish passing through Kaplan turbines is influenced by the operating efficiency. The National Marine Fisheries Service (NMFS) 1995 Biological Opinion requires the turbines to be operated within 1 % of their best operating point efficiency. This requires a clear understanding of turbine absolute efficiency. In August and September 1998, measurements for turbine efficiency were made at Bonneville Dam Powerhouse Unit 5 on the Columbia River. Power output, head and discharge were measured for three different intake configurations: with STSs and a Prototype Surface Collector (PSC) installed; with STSs only installed and with no fish diversion devices installed. Data were collected for a series of wicket gate settings on and off-cam in each case. Relative discharge through the turbine was obtained from Winter-Kennedy taps and absolute discharge was measured using an Acoustic Scintillation Flow Meter (ASFM).

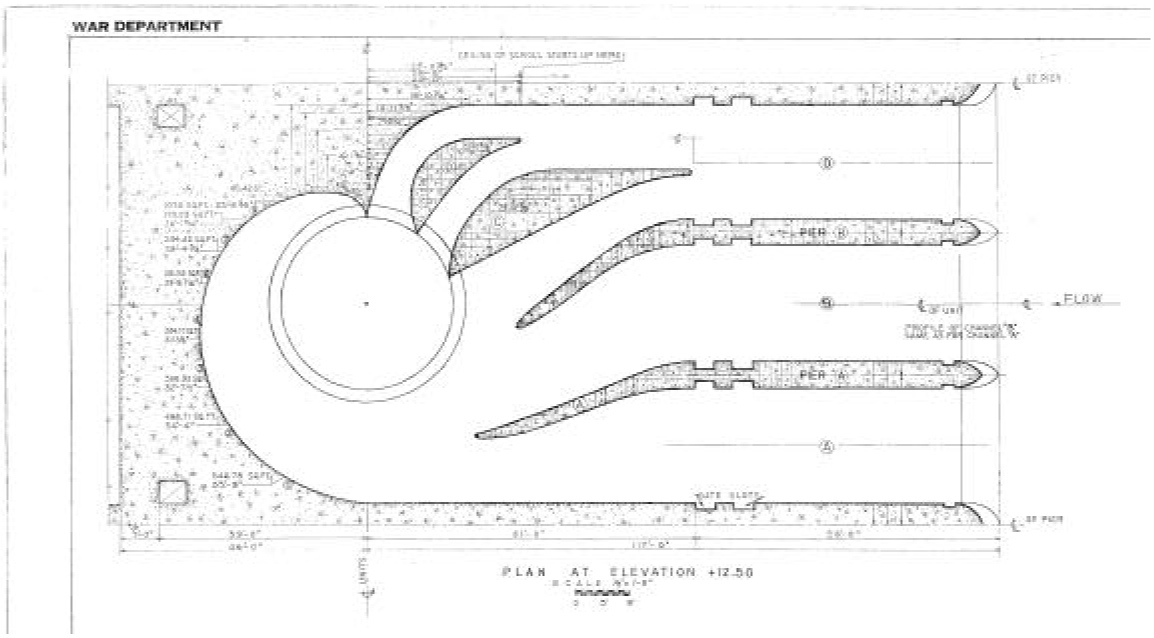
These three Index tests were performed in a similar manner. First a test series was run using the existing Electronic Control Unit (ECU) and existing "on cam" information over the allowable operating range. The ECU has two data sets of "on cam" information stored for the operating conditions of no fish diversion devices installed and with STSs installed. The "on cam" portion of the test with STSs and PSC installed used the data from the STSs installed data table. The ECU data tables for both conditions had been updated with current information from an Index test on Unit 2 using Winter-Kennedy derived information.

The purpose of the Index testing is to "tune" Unit 5 prior to biological testing, to attempt to answer operational questions and to evaluate the effects of installation of the PSC. Previous operation of the unit with STSs and PSC installed had resulted in operational limitations because of instability, rough operation (hydraulic noise) and vibration. The testing was performed to determine if these operational limitations were a result of "off cam" operation and to quantify the effect of the PSC on unit efficiency. The installation of current cam information shortly before the testing began resulted in a substantial reduction of instability, rough operation and vibration.

Plant Configuration

Bonneville Lock and Dam is located on the Columbia River, about 42 miles east of Portland, Oregon at river mile 145.5. The project provides inland navigation, hydroelectric power generation, and recreation. The main structures include two powerhouses, a concrete spillway and stilling basin, a navigation lock, and fish passage facilities. Powerhouse I contains 10 main units (Unit 1-10) and two station service units. Powerhouse I is currently undergoing a major rehabilitation which includes turbine runner replacement. Powerhouse II contains 8 main units (Units 11-18) and two fish water turbines.

The existing unit tested (Unit 5) is an S. Morgan Smith Kaplan design with a runner diameter of 280 inches and speed of 75 rpm capable of 85,000 hp. The water passage of the design contains some unusual features in both the intake and the draft tube (Figure 1). Typical STSs are shown in Figure 2. The Prototype Surface Collector is shown in Figure 3.



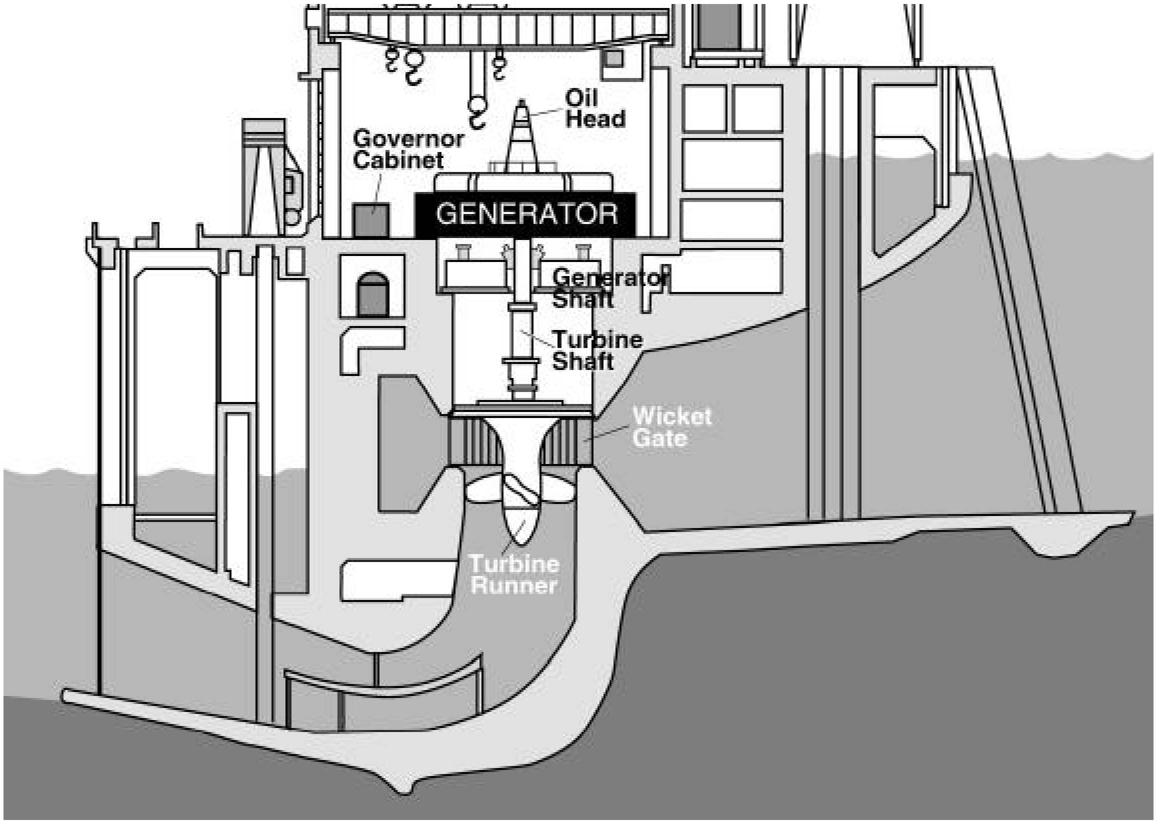


Figure 1: Intake

Figure 2: Typical Standard Travelling Screen, old powerhouse.

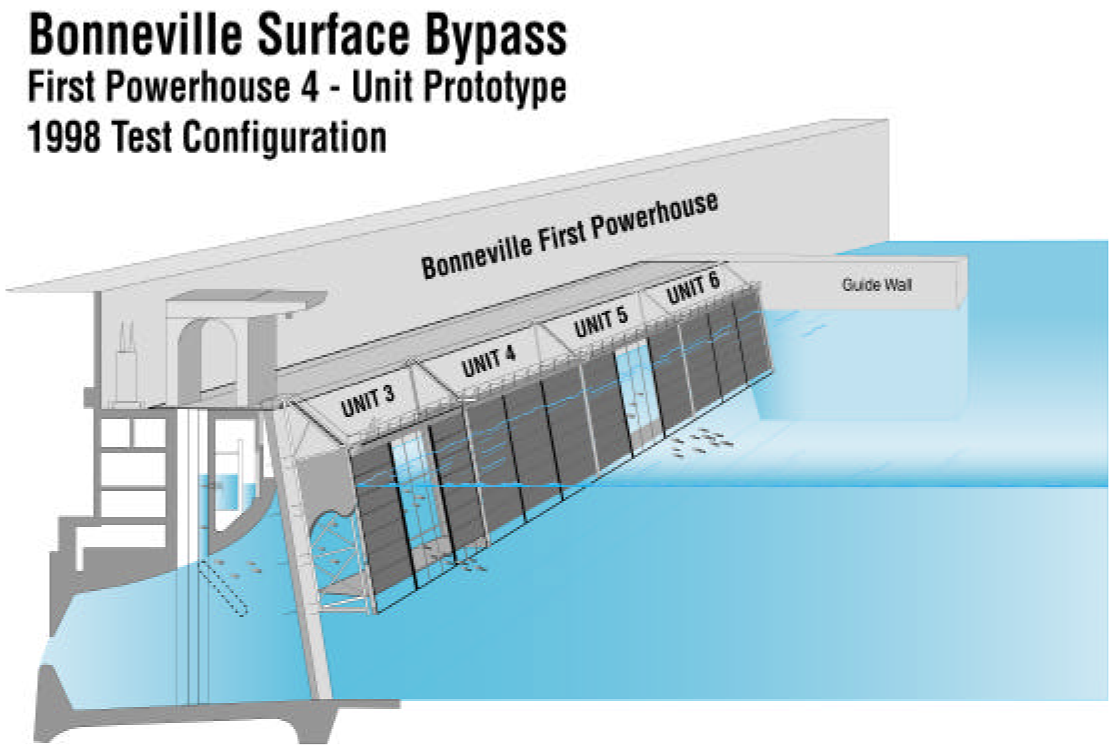


Figure 3: Prototype Surface Collector installed at Bonneville Dam, old powerhouse.

ASFM Installation and Operating Principles

The ASFM's ability to measure absolute discharge under the conditions prevailing in low-head plants was the reason for its use in the Unit 5 tests at Bonneville Dam. The ASFM uses a technique called acoustic scintillation drift (Farmer & Clifford, 1986) to measure the flow speed of water perpendicular to a number of acoustic paths established across the intake to the turbine. Fluctuations in the acoustic signals transmitted along a path result from turbulence in the water carried along by the current. The ASFM measures those fluctuations (known as scintillations) and from them computes the lateral average (i.e. along the acoustic path) of the flow perpendicular to each path. Both the magnitude and inclination of the flow speed are measured. The ASFM computes the discharge through each bay of the intake by integrating the horizontal component of the flow speed over the height of the intake. The discharges from each bay are then summed for the total discharge. Since 1992, the ASFM has been used in several hydro-electric plants and in some instances compared with other discharge methods such as current meters (Lemon, 1995, Lemon, Caron, Cartier & Proulx, 1998; Lemon et al, 1998).

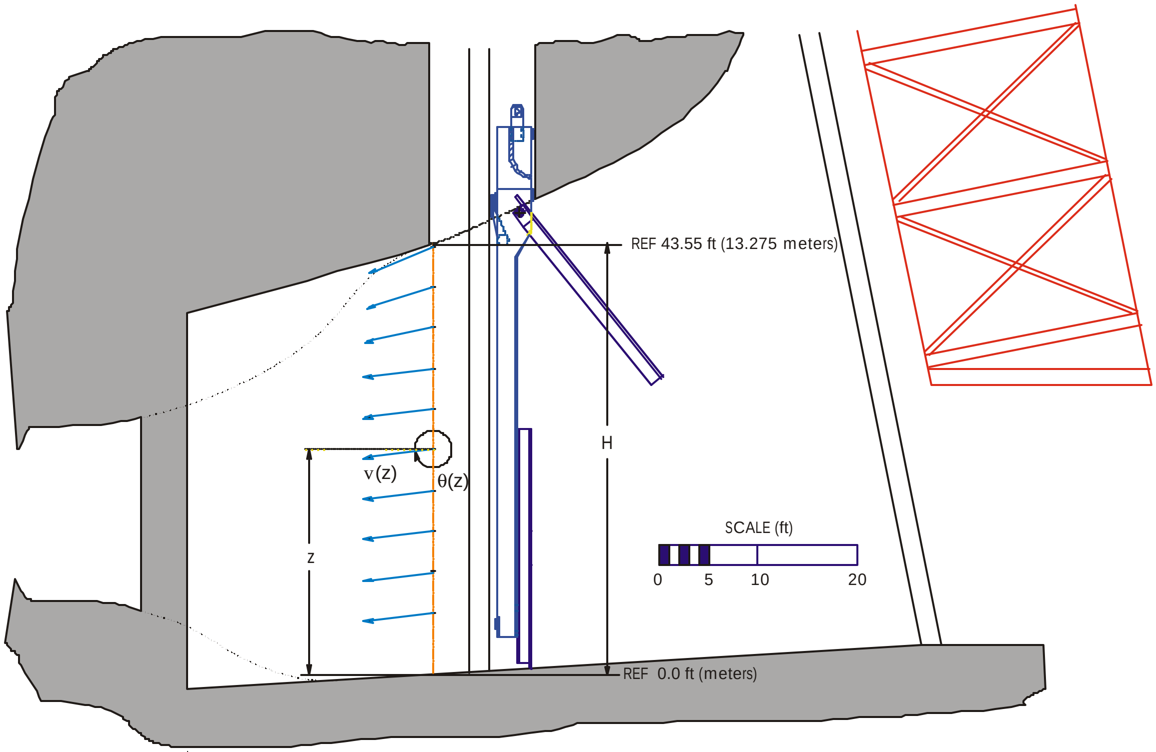


Figure 4: Location of the measurement plane in the intake, and definition of the associated parameters. Shown with STS and PSC installed.

The ASFM was installed in the head gate slots of Unit 5. Unit 5 has three intake bays, each of which was to be equipped with 10 acoustic paths. The transducers were installed on three support frames, one for each bay. The transducer support frames were designed and supplied by the Walla Walla District. Figure 4 shows the location of the measurement plane in the intake and its relationship to the STS and PSC (when installed), and the definition of the quantities measured.

Data Collection

The index test procedure generally followed the salient portions of the ASME PTC-18 and IEC 41 test codes. The following measurements were made during the testing: Upper and Lower water surface elevations, Winter-Kennedy differential pressure and independent leg Winter-Kennedy tap pressures, scintillation flows, generator output, wicket gate position, and runner blade angle. Repeatable wicket gate positions were obtained by use of servomotor blocks. The existing electronic control unit (ECU) adjusted the runner blade angle to the stored “on cam” data table for the selected “on cam” test condition. Test data was also collected from the electronic control unit (ECU), the control room, from regular manual check measurements and zero checks made at the beginning and end of each day's testing. Electronically measured data was available in real time with corresponding graphical information instantly available for examination during the testing. The preliminary scintillation flow measurements were manually input into the data set prior to changing to another wicket gate setting, a procedure which could easily be automated in future.

Typical intake velocity distributions as measured by the ASFM are shown in Figures 5, 6 and 7 for each of the three intake configurations measured. In each case, the distributions are shown for Bay A and Bay C, because of the differences in intake configuration among the bays.

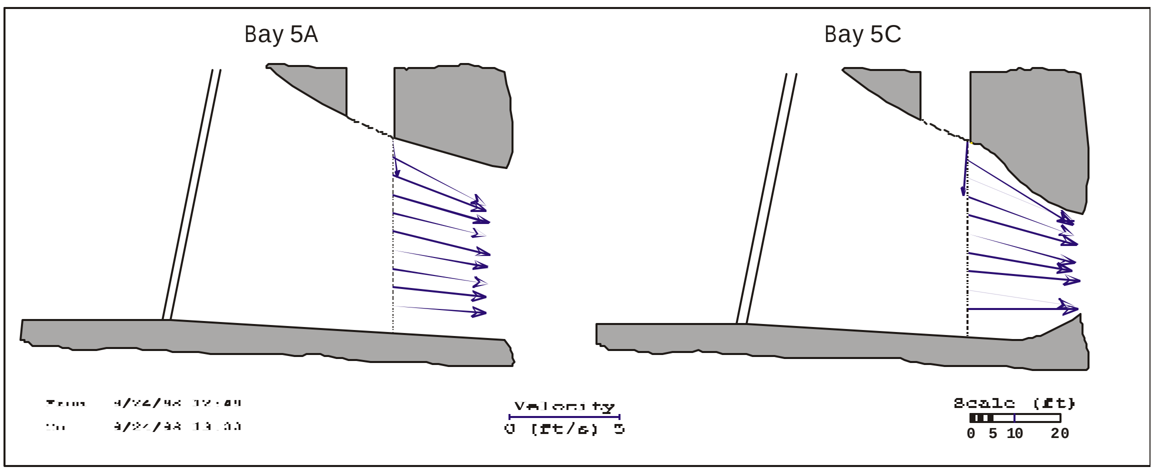


Figure 5: Velocity vectors measured in the intake, Bays A & C, no STSs or PSC.

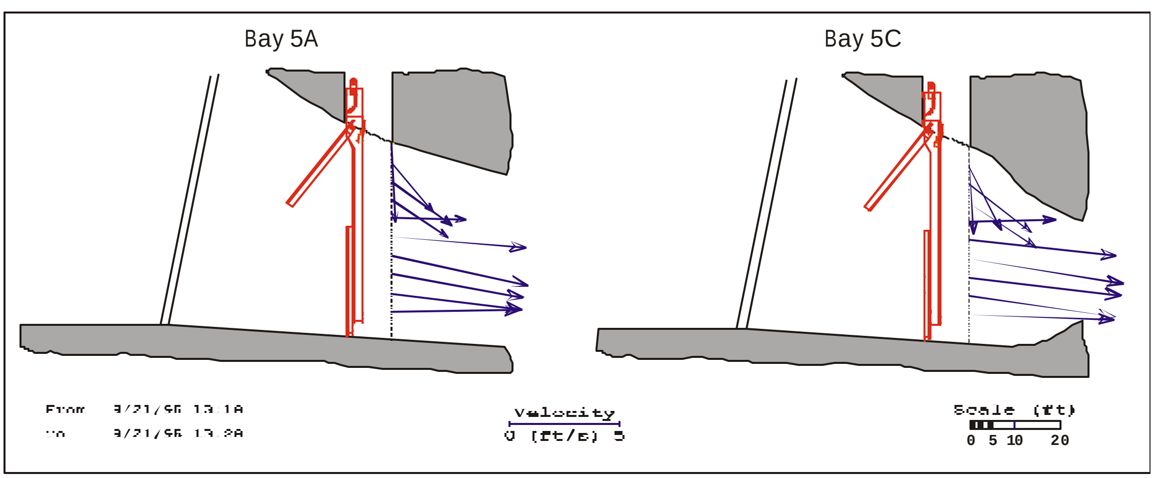


Figure 6: Velocity vectors measured in the intake, Bays A & C, STSs installed.

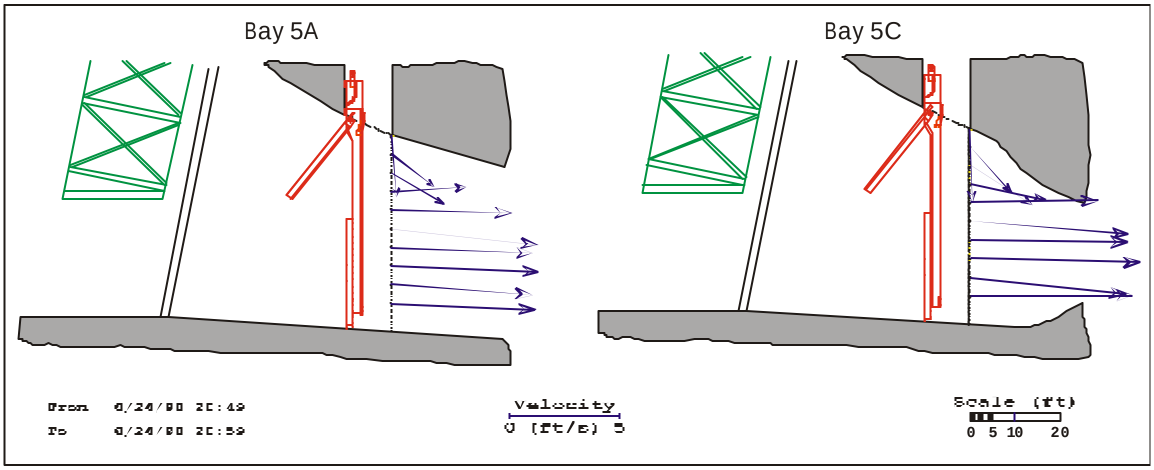


Figure 7: Velocity vectors measured in the intake, Bays A & C, STSs and PSC installed.

The discharge through the intake was computed in each case from the profiles of the laterally averaged velocity v:

$$Q = \int_0^H v(z) \cos[q\,(z)]\,L\,dz \qquad (1)$$

where *v*(*z*) is the magnitude of the laterally averaged flow at elevation *z*, *q*(*z*) is the corresponding inclination angle, *L* is the width between the transducer faces and *H* is the height of the tunnel roof above the floor. The lateral averaging performed by the ASFM is continuous, while the sampling in the vertical was at ten discrete points. Calculating *Q* then requires estimation of the integral in equation 1 when the integrand is known at a finite number of points. The integral was evaluated numerically using an adaptive Romberg integration, with a cubic spline interpolation in the integrand between the measured points. The contributions from the boundary zones near the floor and at the roof were evaluated as described in Lemon et. al. (1999).

Results

Figure 8 presents the summary results of the three Index tests for comparison.

1. The operating head during the performance of the three Index tests was such that the design blade angle of about 34 degrees could not be reached due to generator limitations. This resulted in extrapolation of the data to complete the turbine cam and performance curves.

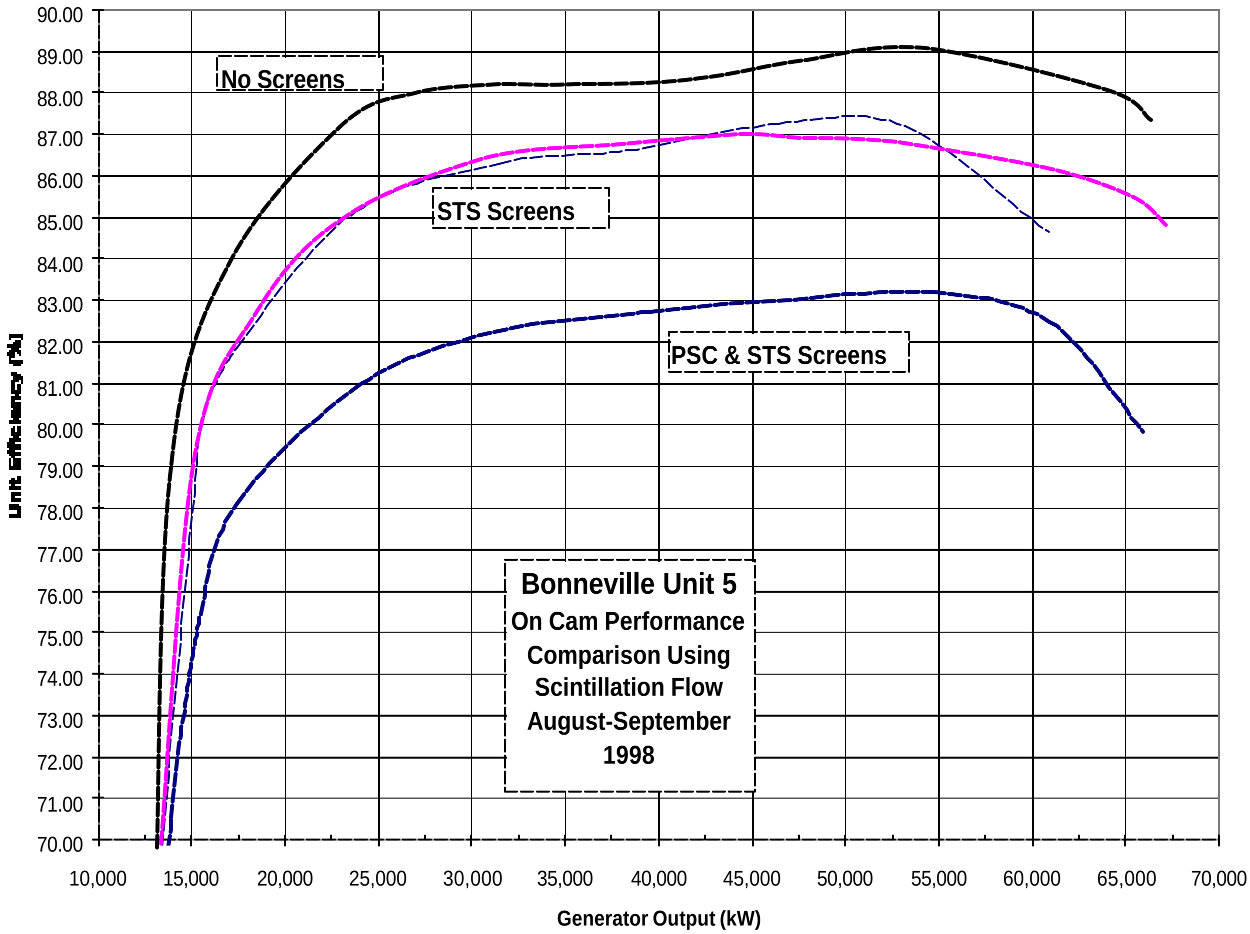


Figure 8: Comparison of unit efficiency for all three test configurations.

2. in a unit efficiency loss in excess of 5% when compared to the condition without fish diversion devices installed
3. The PSC results in approximately 4% loss in unit efficiency when installed with the STS screens.
4. The installation of the STS screens by themselves result in a unit efficiency loss of approximately 1.5-2.0 %.

5. The most significant change in the cam curves occurred at blade angles less than 18 degrees.
6. The Winter-Kennedy differential pressure taps results provided a reasonably accurate prediction of performance and cam curves.
7. It was found that the ECU head signal was consistently off by 2-5% from the independent measurements.

Conclusions

The use of the Scintillation flow measurement technique greatly improved the definition and estimation of effects of fish diversion devices on Kaplan turbine performance.

1. The "on cam" curves used for the baseline condition for each test that were derived from recent Winter-Kennedy measurements provided reasonable performance over the normal operating range of the machines.
2. The development and installation of new "on cam" data derived from these tests should improve unit performance from 0-2%.
3. Care must be taken in the calibration of the scintillation measurement equipment to the mounting frame and in the determination of flow boundary conditions.
4. The calibration of the input measurement devices to an ECU should be regularly checked against physical measurements and updated.
5. The operational limitations, hydraulic noise and vibration experienced with the PSC and STSs installed were substantially reduced with achieving a better "on cam" blade gate relationship.

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