SURFACE WATER PUMPS TO IMPROVE DISSOLVED OXYGEN CONTENT OF HYDROPOWER RELEASES

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Abstract

This paper describes the development, installation, and performance testing of a surface water pump system at TVA's Douglas Dam. Surface water pumps move a large volume of highly oxygenated surface water down to a level where it is withdrawn through the hydropower intakes to improve the water quality of hydropower releases. TVA has tested several different arrangements and types of surface water pumps at Douglas Dam since 1986. Operation of the current system during 1994 has demonstrated significant dissolved oxygen improvement capabilities. Varying conditions in the forebay stratification and hydropower operations control the system effectiveness. Under average conditions the system has demonstrated a capability to increase the dissolved oxygen content of the hydropower discharge by 1.5 to 2 mg/L. Installation and operating costs of the pumps are presented along with a discussion of experiences with equipment, flotation, and mooring design.

Introduction

Douglas Dam is located on the French Broad River, about 40 km (25 miles) east of Knoxville, Tennessee. The reservoir contains over 1,700,000 Hm^3 (1,400,000 acre-feet) and is 45 meters (150 feet) deep near the dam at summer pool levels. Hydropower facilities include four Francis hydroturbines with associated generating equipment rated at about 30 MW each with a total plant flow rate of about 450 m^3/s (16,000 cfs). The water releases from this dam display extended periods of low dissolved oxygen content during the summer months due to thermal

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stratification, biological oxygen demand, and chemical oxygen demand in the reservoir. Periods of less than 0.5 mg/L of dissolved oxygen have historically averaged more than 30 days per year. These levels of dissolved oxygen are far below the Tennessee state standards for warmwater fisheries and would violate Federal Energy Regulatory Commission requirements for re-licensing if TVA were subject to those requirements. The adversely affected tailwater conditions persist for up to 48 km (30 miles) downstream of the project. The surface water pumps are now operated in concert with a forebay aeration system to achieve a TVA target of 4 mg/L in the release.

TVA has maintained a program for many years to address methods for water quality improvements below reservoirs. The "TVA Lake Improvement Plan" is staffed by a task force composed of representatives from the many different areas of expertise within TVA and from each of the states affected. Project alternatives presented to this task force are subjected to the varied interests of electric power generation, water quality, recreation, engineering, and economics in order to create a proactive environment with input solicited from the groups affected before a project is begun. Surface water pumps were selected by this task force for installation at Douglas Dam after several years of successful testing and development.

Surface water pumps improve the dissolved oxygen content of hydropower releases by moving surface water down to a depth where it will be withdrawn by the hydroturbines. The mixture of oxygen-rich surface water with the low dissolved oxygen hypolimnetic water normally withdrawn increases the oxygen content of the release. To be effective, the pumps must move sufficient quantities of surface water to dilute the hypolimnetic turbine flow by at least 30 percent. For the plume of warm, oxygen-rich surface water to reach the withdrawal zone of the hydroturbine (see Figure 1), the pump must provide enough vertical momentum to overcome the buoyant forces acting on the plume due to thermal stratification.

Description of Surface Water Pumps

Surface water pumps have been installed and tested at several locations with varying degrees of success. Dr. James Garton of Oklahoma State University advocated the use of high specific speed pumps for this application and tested several small installations between 1970 and 1985 (Quintero and Garton, 1973; Robinson et al., 1982). The U. S. Army Corps of Engineers has tested small diameter, high speed pumps at the J. Percy Priest Reservoir near Nashville, Tennessee (Price, 1988). Pumps of Dr. Garton's design at Union Electric's

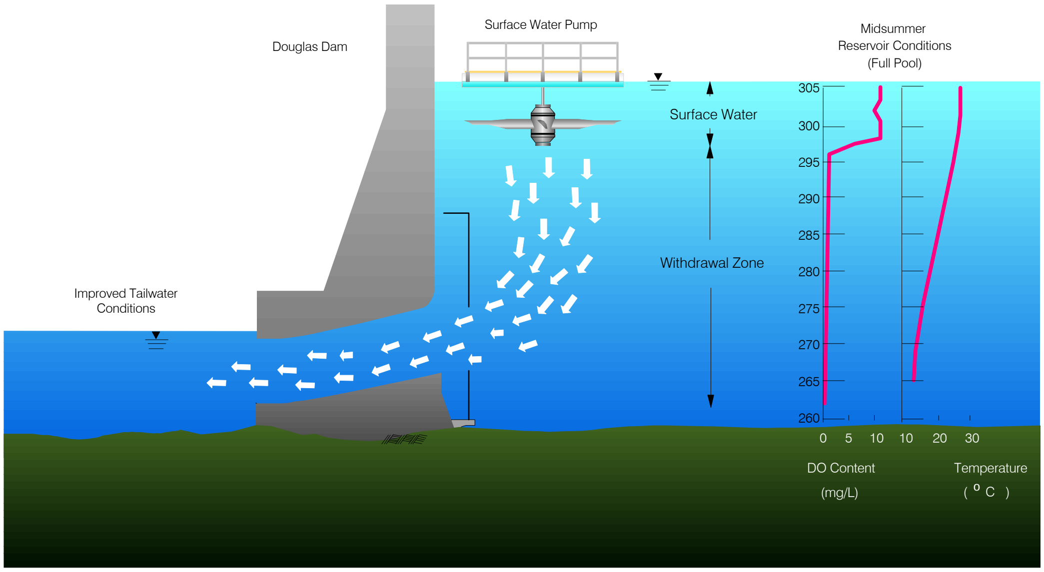

Figure 1. Schematic of Surface Water Pump Concept

Bagnell Dam (Garton and Miller, 1982) were modified and tested at Douglas Dam in 1987 by TVA (Harshbarger et al., 1987; Mobley, 1987).

During 1993 and 1994, an aeration system, consisting of nine surface water pumps, was installed at Douglas Dam. The locations of the pumps with respect to the four generating units are shown in Figure 2 and the general arrangement of the pumps is shown in Figure 3. A more detailed view of a single pump is shown in Figure 4. Each pump includes a 30 kW (40 hp) electric motor and gear reduction to drive a 4.6-meter (15-foot) diameter stainless steel impeller. Variable frequency electric drives permit variable speeds up to 24 revolutions per minute. The pumps are designed to move 15 m^3/s (530 cfs) of surface water each to replace about 30 percent of the total plant flow.

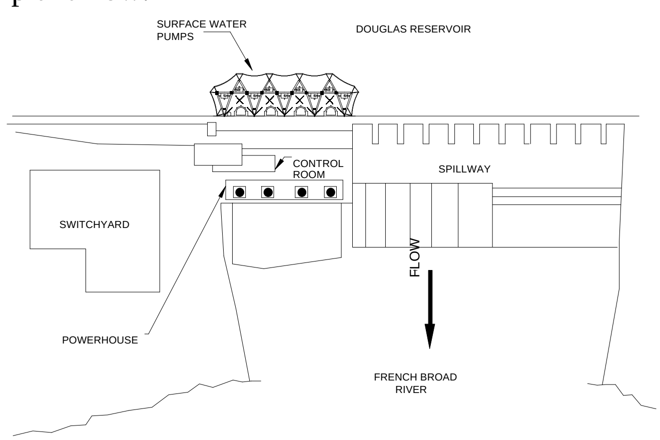

Figure 2. Location of Surface Water Pumps at Douglas Dam

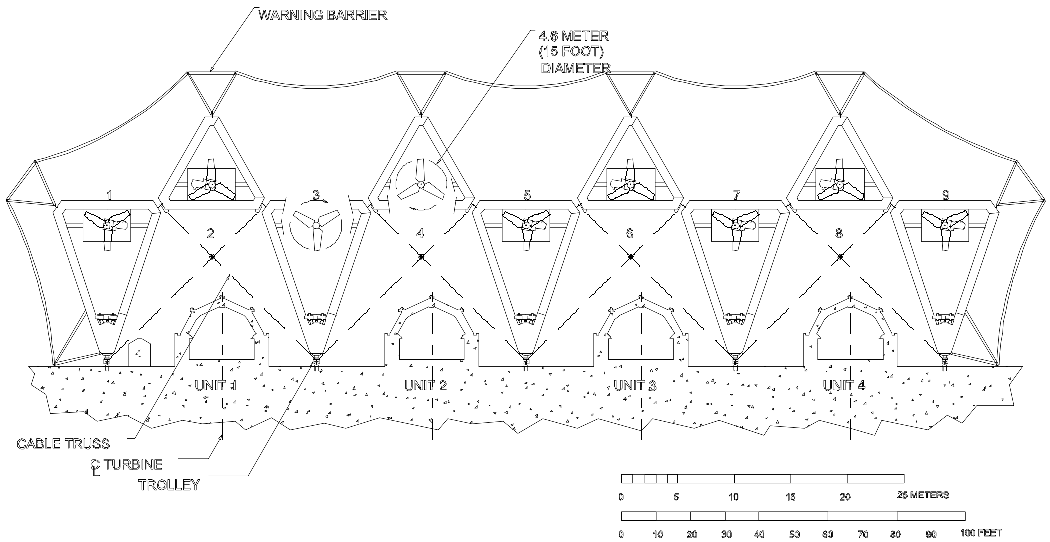

Figure 3. General Arrangement of Surface Water Pumps at Douglas Dam

Some of the most difficult problems to overcome in the use of surface water pumps are the ability to accommodate seasonal fluctuations of the reservoir headwater elevation and to withstand the pounding of waves formed by wind and watercraft on the reservoir. The TVA surface water pump design overcomes these problems by using an array of nine triangular floating platforms that are linked together with gimbals at the apexes of the triangles. These connections form a stable, yet flexible system of platforms that cover an area larger than a football field (Figure 3). The use of large, triangular shapes eliminates the need for troublesome connecting links between the smaller square or round floats of previous designs. The floats are attached at five places to an independent system of five trolleys running on stout vertical rails mounted on the face of the dam. This allows a 19-meter (62-foot) range of vertical movement as shown in Figure 5. The variable speed capability afforded, by the electric motor controls, allows the pump outputs to be reduced to avoid stirring up bottom sediments while operating at low headwater elevations.

Surface Water Pump Performance

The performance of the surface water pumps can be measured in terms of mechanical pumping rate or dissolved oxygen improvements. The output velocity and pumping rate of the surface water pumps are a direct measure of the mechanical equipment capabilities. These measurements are not affected by reservoir conditions. Conversely, the dissolved oxygen improvement obtained at

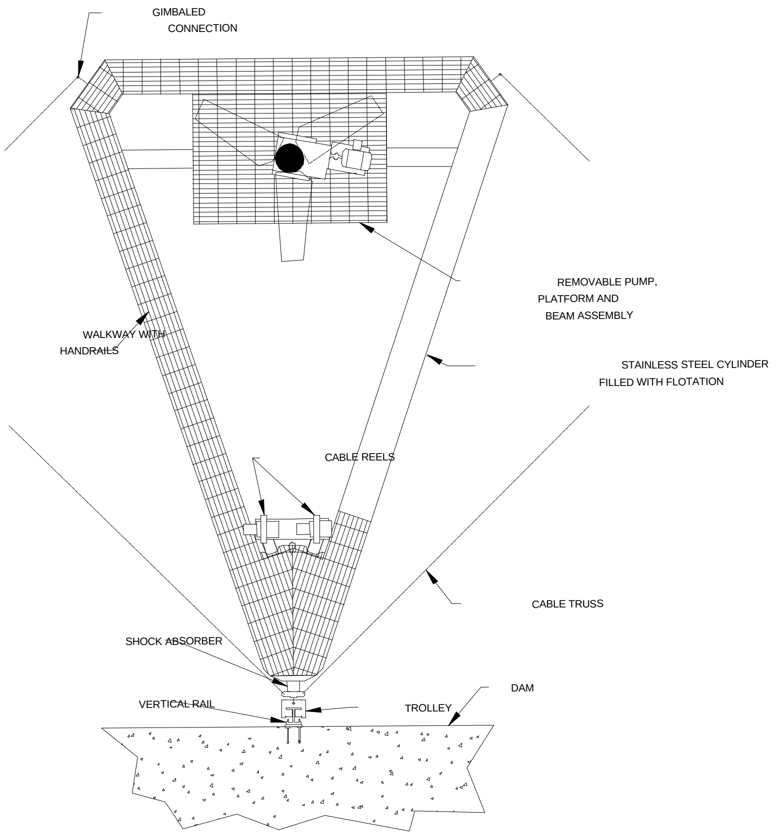

Figure 4. Surface Water Pump Details

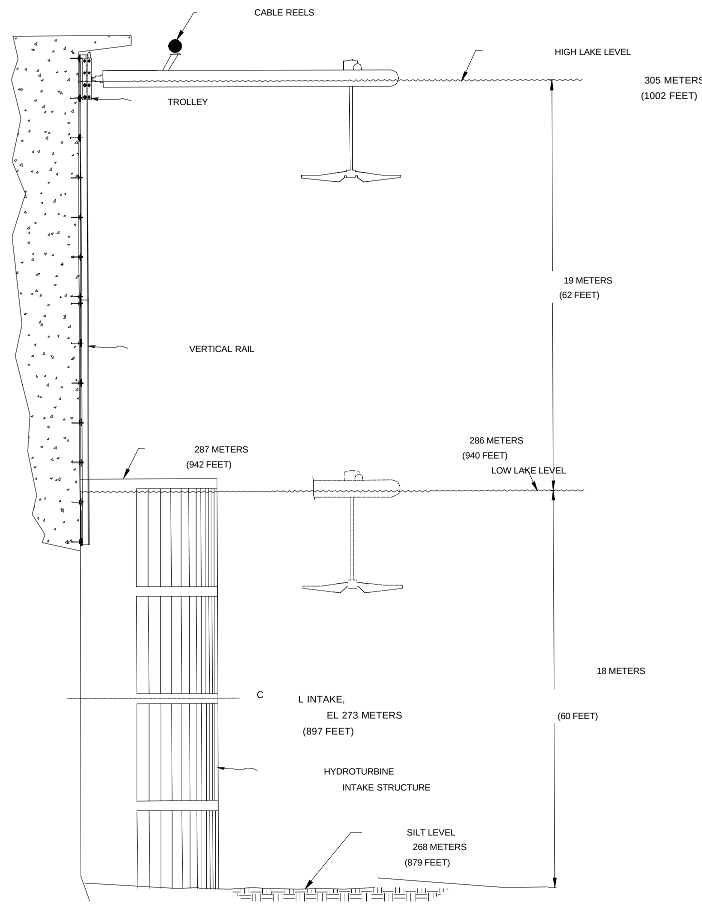

Figure 5. Surface Water Pump Elevation Chart

the hydropower outlet is directly related to the dissolved oxygen content and temperature profile in the reservoir as well as surface water pump and hydroturbine flow rates (Mobley, 1990). Measurements of pump output velocities and dissolved oxygen increases were obtained for the surface water pump system at Douglas Dam.

Velocity measurements were conducted during 1993 and 1994 to determine the capability of the mechanical equipment. Previous development work and mathematical modeling had determined that an average velocity of 0.9 m/s (3 ft/s) was required to move a 4.6-meter (15-foot) diameter plume of surface water into the turbine withdrawal zone under the typical reservoir conditions expected at Douglas. The comprehensive velocity measurements were repeated several times since the results indicated that the equipment purchased in 1992 did not meet performance specifications (Mobley et al., 1993). Several modifications were made to improve the performance of the pumps. The electric motors were changed from 22.5 kW to 30 kW (30 hp to 40 hp), and the impellers were ultimately replaced with units from a different manufacturer to obtain satisfactory results. The pumping rate improvement obtained with the new impellers is shown in Figure 6.

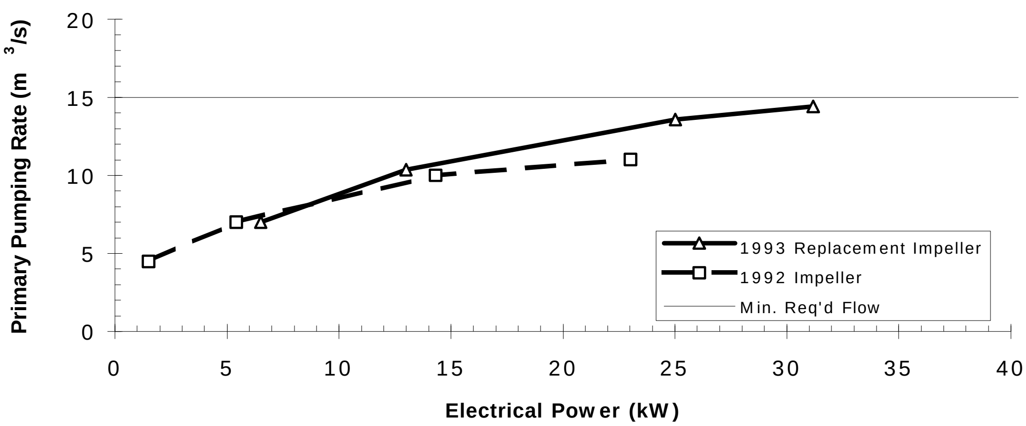

Figure 6. Typical Surface Water Pump Plume Velocity Profile

The velocity measurements were repeated after each modification to the pumps. A typical velocity profile measured at a distance of 2.1 meters (7 feet) below the impeller is shown in Figure 7.

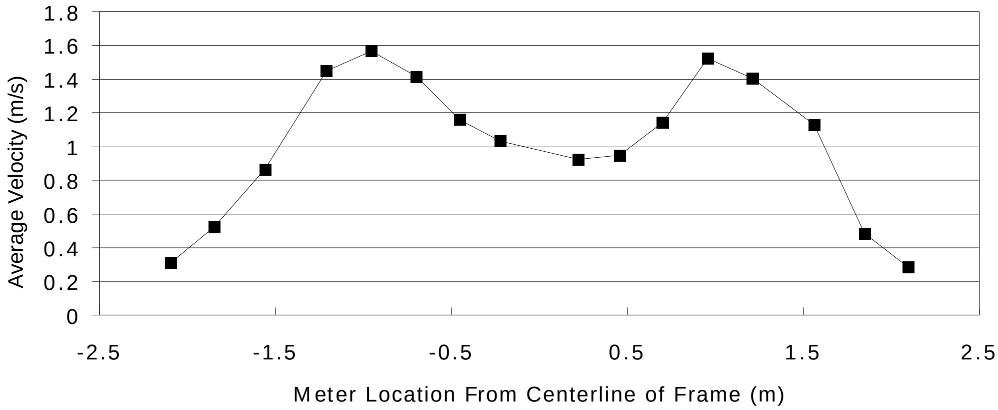

Figure 7. Surface Water Pump Impeller Performance Comparison

Modifications to the pumps to replace the impellers and remedy equipment failures delayed dissolved oxygen performance testing until September 8, 1994. Reservoir conditions in September were less than ideal for these tests since the effectiveness of the pumps can be diminished when the dissolved oxygen profile in the reservoir is not as dramatic as in mid-summer. Figure 8 shows dissolved oxygen and temperature profiles in the reservoir upstream of the dam on September 8, 1994, as compared to typical mid-summer conditions. The surface water pumps are expected to show better performance with higher dissolved oxygen content in the surface water and near-zero content at the intake elevation despite the increased temperature gradient.

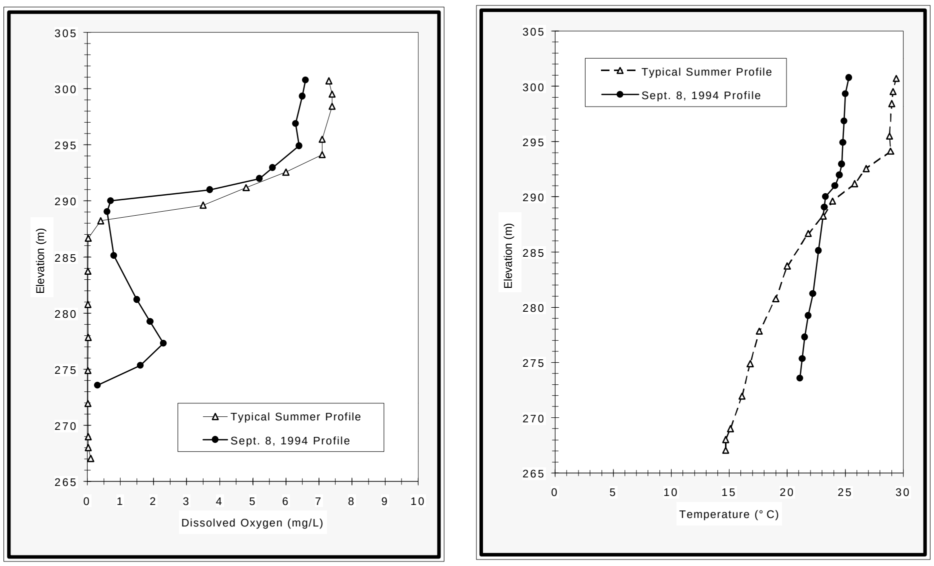

Figure 8. Douglas Forebay Profiles, September 8, 1994

All four turbine units were in operation for the majority of the test period on September 8, providing a total flow rate of about 450 m^3/s (16,000 cfs). All nine surface water pumps were operational at the outset of the test, but pumps #7 and #9 failed due to electrical problems early into the testing thereby affecting the results measured at hydroturbine unit 4. Dissolved oxygen measurements were collected at each hydroturbine scrollcase to track the performance of the surface water pumps. At each test setting, the Winkler titration method was used to check levels obtained from a continuous monitoring system with membrane type dissolved oxygen sensors. The changes in dissolved oxygen levels produced by operation of the pumps are shown in Figure 9. The steady-state improvement of each unit varied significantly, but averaged 1.6 mg/L over the three units where all surface water pumps were operating. The dissolved oxygen levels recorded for unit 4 emphasize the improvements gained on the three units where the pumps were operating properly and indicate that the single pump operating on unit 4 was having very little effect. Operating experience has shown that the pumps are more effective when operating adjacent to one another since the pump plumes tend to combine and reduce entrainment from the hypolimnion. Surface water pump effectiveness is also improved with more than one hydroturbine unit in operation because operation of adjacent hydroturbine units tends to extend the withdrawal zone vertically upward so that the pump plume is not required to penetrate as far to be withdrawn.

Installation and Operating Cost

The capital costs for the complete surface water pump system were about $2.5 million. mechanical equipment and flotation platforms accounted for about $1.5 million, with the rest attributed to installation costs. A significant portion of the installation costs is due to modifications necessary to make adequate electric power available for the surface water pumps. Electrical operating costs are absorbed by the plant but would be about $5,000 per month at local commercial rates. Lubrication and other standard maintenance activities for rotating equipment are required as well as occasional removal of accumulated trash and debris from around the floating platforms. To achieve the 1.6 mg/L dissolved oxygen uptake documented on September 8, electrical costs to operate the surface water pumps were about $10.50 per hour. For comparison, the costs to achieve the same uptake using an oxygen diffuser system would exceed $188 per hour.

Conclusions

Surface water pumps are expensive to install, but they have proven to be one of the most economical means to deliver dissolved oxygen to the hydroturbine flow because they are inexpensive to operate and maintain, making them a desirable option for improving reservoir releases. Site-specific

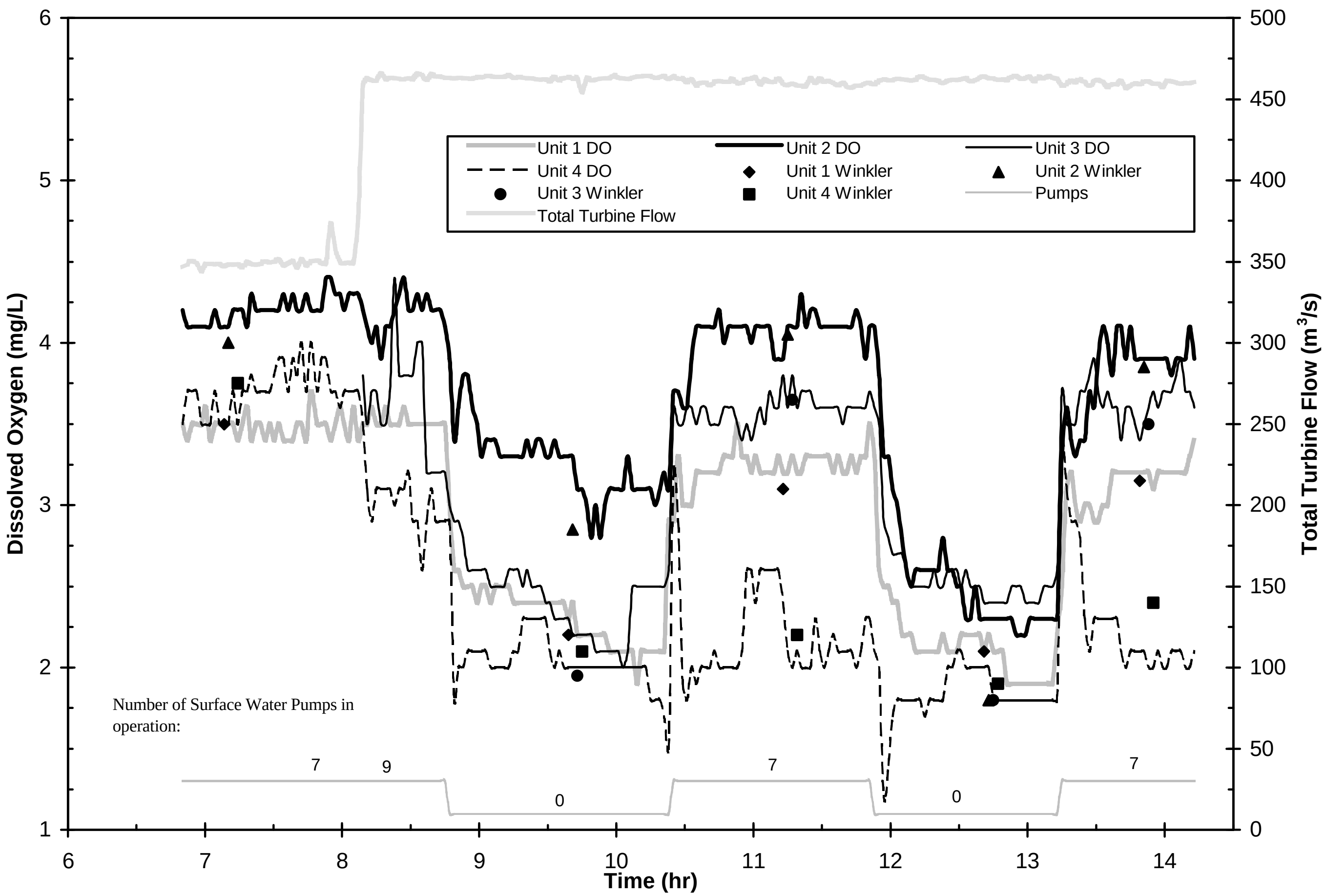

Figure 9. Douglas Surface Water Pump Performance, September 8, 1994

requirements typically limit the applicability of surface water pumps to medium head, medium flow hydropower projects that exhibit strong dissolved oxygen stratification profiles in the forebay. Sites that have temperature sensitive tailwater fisheries or other temperature requirements may have additional limitations due to the temperature increases resulting from withdrawal of more of the warmer surface water. Significant dissolved oxygen improvements can be obtained with a properly designed surface water pump system. For an effective installation, the system design must take into consideration: headwater fluctuations; loadings due to wave action; and pump plume velocities required.

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