A primary requirement for sustaining healthy fisheries and aquatic ecosystems is the presence of sufficient DO (dissolved oxygen). In temperature-stratified reservoirs, dissolved oxygen is consumed deep in the reservoir and is not replenished because of the lack of mixing inherent in stratification. When water from deep in the reservoir is released through a powerplant, the low DO concentrations become a problem for the river downstream. This article describes recent testing at Deer Creek Powerplant on the Provo River to alleviate just such a problem. The testing was done to evaluate the feasibility of turbine aeration, which would improve low DO concentrations by mixing air with the water flowing through the powerplant.

Aerating Powerplant Flows to Improve Water Quality

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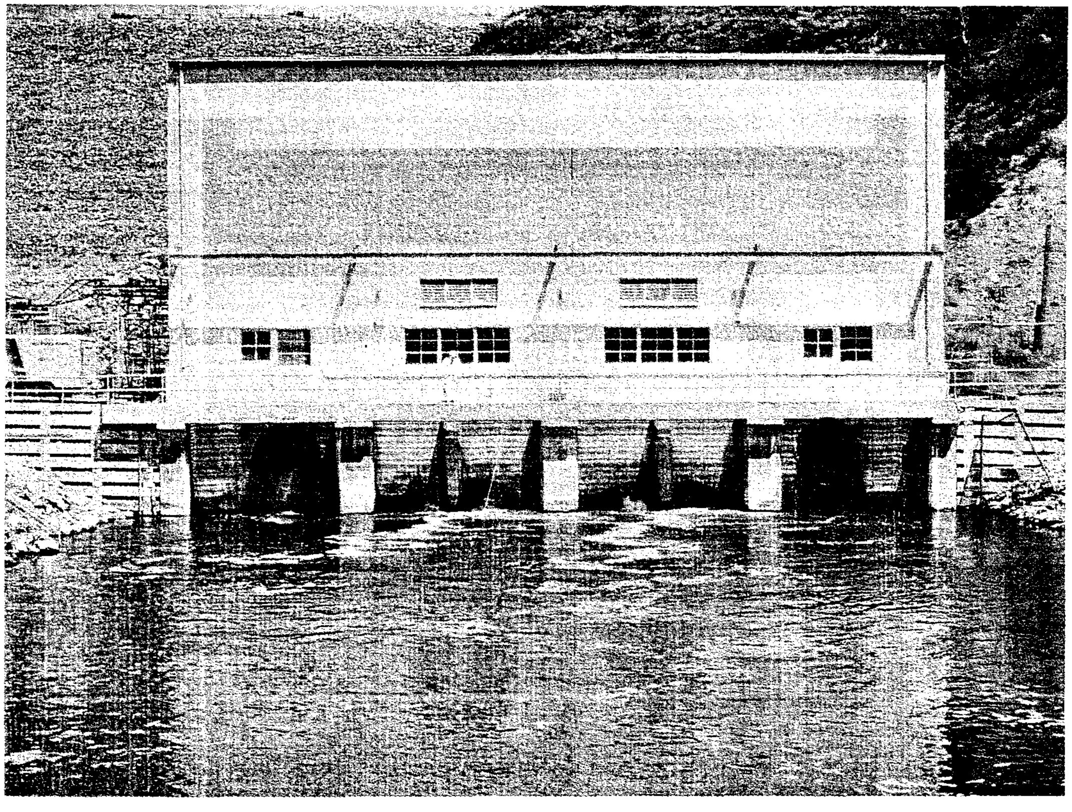
Fisheries problems related to dissolved gases—dissolved oxygen in particular—are not a new phenomenon. For many years, Reclamation has dealt with problems of nitrogen supersaturation (too much dissolved gas) and resulting gas bubble disease in fish downstream from weirs, energy dissipation structures, and outlet works. Dissolved oxygen problems also have been a serious, but limited problem for Reclamation, but may become more common in the future as we learn more about the biology and water quality of western rivers. Dissolved oxygen problems have been a serious concern for many years in the Southeastern U.S., where long growing seasons, more plant life, and warm temperatures produce severe reservoir stratification with low DO concentrations. The TVA (Tennessee Valley Authority) has been studying DO improvement technologies for many years, and is actively pursuing the development of turbine aeration technology. Reclamation has assisted TVA in this research, primarily through participation in model turbine testing at Colorado State University in 1992 and 1993.

The Problem

Deer Creek Reservoir is located about 24 km (15 miles) upstream from the city of Provo, Utah, and receives inflow from a watershed with heavy agricultural development and increasing commercial and urban development. The powerplant contains two 2,475-kW Francis turbines, with a rated head of 36.6 m (120 ft) and a rated discharge of 8.5 m^3/s (300 ft^3/s). During late summer months (July to October), the releases from the reservoir are made entirely through the powerplant (fig. 1), and DO concentrations are in the range of 0 to 2 mg/L. (Recommended minimum DO concentrations are typically in the range of 5 to 6 mg/L.) Past studies show that the low DO concentrations at this site have impacted about 3 to 5 kilometers (2 to 3 miles) of heavily used blue ribbon trout fishery downstream from the dam. Future relief for some of the low DO problems at Deer Creek may be obtained through management of the releases from the newly completed (and still filling) Jordanelle Dam about 16 kilometers (10 miles) upstream from Deer Creek Dam. However, in the near future, DO enhancement must come from technologies that are designed to directly add oxygen to the water, such as turbine aeration.

During the winter of 1992-93, drought conditions restricted Deer Creek Reservoir releases to about 85 percent of the required instream flow. Reclamation agreed to provide mitigation for this low flow event, and during the summer of 1993, several mitigation alternatives were proposed. In addition to water exchange

Figure 1. – Deer Creek Powerplant on the Provo River upstream of Provo, Utah. During late summer flow released through the powerplant has a dissolved oxygen concentration of 0-2 mg/L.



proposals designed to make up for the water shortages caused by the drought, several proposals involved DO enhancement projects at or downstream from the powerplant. These proposals included forgoing power generation to release water through the spillway or outlet works, installation of aeration weirs in the river downstream from the powerplant, and several proposals to maintain powerplant operation and directly improve the DO concentrations of the powerplant releases. As a result of past experience with instream aeration projects and our involvement with TVA's turbine aeration research, the Hydraulics Branch assisted in developing the DO enhancement proposals.

Options for DO enhancement at the powerplant included direct injection of molecular oxygen into the penstocks upstream from the powerhouse, injection of compressed air into the draft tubes of the turbines (active turbine aeration), and passive turbine aeration achieved by opening existing air lines and allowing the natural vacuum to draw air into the draft tubes. We also proposed raising the overflow gates that control the water level in the tailrace pool downstream from the powerhouse. Raising the tailwater could provide longer contact times and improved gas transfer for the air added in the turbines. Raising the gates also would provide a second source of aeration because the flow over the gates would entrain air as it plunged into the river downstream from the gates. After analyzing each of these options, we chose to conduct a field test of the turbine aeration and tailrace control gate aeration concepts to evaluate their feasibility and effectiveness.

Aeration Testing

A field test of the concept was organized for August 1993, by the Hydraulics Branch in Denver and the Regional Planning Office in Salt Lake City, with assistance from the Operations and Maintenance Engineering Branch in Denver, the Provo Area Office, the Provo River Water Users Association, and the Central Utah Water Conservancy District. Objectives included determining the effectiveness of aeration, evaluating the impact on power output and mechanical behavior of the turbines, and obtaining data needed to design a permanent turbine aeration system.

We arranged to rent two large diesel-engine-powered air compressors to inject air into the operating turbine units through the vacuum breaker systems and through the snorkel tubes (fig. 2). We planned to inject air primarily through the vacuum breaker system because these air passages were much larger than those leading to the snorkel tube. To evaluate the effectiveness of aeration and its effect on the performance of the turbines, we made measurements of airflow rate, DO concentration upstream and downstream from the turbines and below the tailrace control gates, generator output and turbine efficiency, and bearing and shaft vibration.

We conducted 3 days of testing over a range of airflow rates under several different turbine operating conditions. We tested airflow rates ranging from 0 to almost 6 percent of the total turbine discharge. [Airflow was expressed as the volumetric percentage of air to water, calculated as though the air was at standard pressure and temperature (101.3 kPa, 15 °C)]. We operated the turbines at wicket gate openings ranging from 35 to 77 percent. We also raised and lowered the tailrace level using the control gates to determine the effect on turbine aeration and the DO improvement that could be achieved by aeration of the flow plunging over the gates.

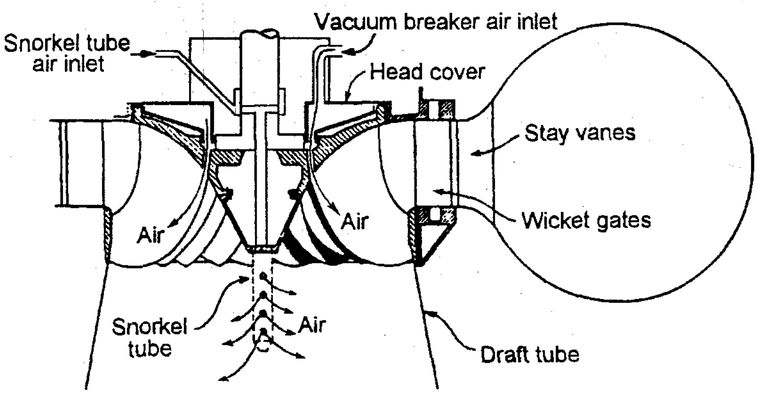


Figure 2. – Air was injected into the turbines through the vacuum breaker system and through the snorkel tube.

Results

During the first day of testing we found that the air passages through the vacuum breaker system on unit 1 were partially plugged, which severely limited the airflow we were able to obtain. We switched our air connections on this unit to the snorkel tube and were still able to get sufficient airflow with the compressors operating at maximum capacity.

Turbine aeration proved to be very effective, and we achieved DO concentrations as high as 5.5 mg/L downstream from the turbines. The DO concentration entering the powerplant was 1 to 2 mg/L during the tests, and the saturation concentration was about 9 mg/L (saturation concentrations drop as temperature increases). Because DO transfer is partially driven by the deficit from saturation (more DO transfer will occur when the initial deficit is larger), an aeration efficiency was calculated by taking the ratio of the DO increase to the initial deficit from saturation. Figure 3 shows the aeration efficiencies plotted against the airflow expressed in percent. The majority of testing was performed with airflow rates of 4 percent or less, and in this range aeration efficiency increased about 10 percent for each 1 percent additional airflow. With this information, we can predict the DO increase for different incoming DO concentrations and water temperatures.

In the range of 55- to 77-percent wicket gate setting, power losses caused by aeration were about 0.5 percent for each 1-percent airflow. We also tested aeration at a wicket gate setting of 35 percent and found that power output increased about 1 to 3 percent. This increase was caused by aeration alleviating draft tube surging at this gate setting.

The vibration monitoring revealed no adverse effects of aeration. The tests also confirmed that axial blowers with a maximum supply pressure of 70 to 100 kPa (10 to 15 lb/in^2) would be suitable for a permanent installation. In addition, the natural vacuum in the draft tube was sufficient to draw significant quantities of air into the turbines without blowers (passive aeration). Aerating the flow in this manner would be most effective with the turbines operating at low discharges when airflow rates could be as high as 2 to 3 percent.

Testing of the overflow gates at the downstream end of the tailrace pool showed that about 20-percent aeration efficiency (about 1.5 mg/L increase during these tests) could be obtained by raising the gates to create a 0.9-meter (3-ft) drop, although power losses would be about 2.5 to 3 percent because of reduced head on the powerplant. Raising the tailrace water level did not significantly affect the airflow rates into the turbines or the DO enhancement achieved by turbine aeration.

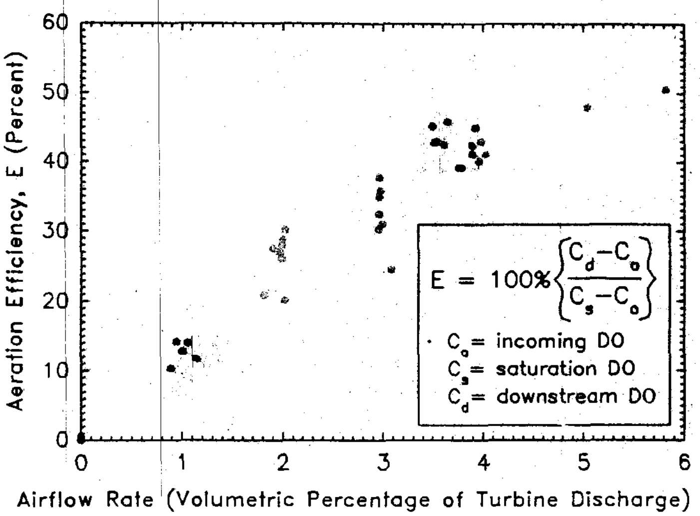


Figure 3. – Aeration efficiency achieved by turbine aeration as a function of airflow rate. Aeration efficiency is the increase in dissolved oxygen as a percent of the initial deficit from saturation.

Implementation and Further Testing

Based on the results of the 1993 test, passive aeration will be used during the summer of 1994. The tailrace gates will also be raised to aerate the flow as it leaves the tailrace. We expect to achieve DO improvements of about 1.7 to 2.7 mg/L from the combined turbine and tailrace control gate aeration. Turbine aeration will be most effective late in the summer when discharge through the powerplant is at the lowest level. The primary cost of the program will be the reduction in power output caused by turbine aeration and raising the tailwater level. The value of the power lost during the season has been estimated to be about $3,000. About 80 percent of the power loss will be caused by the increase in tailwater level.

Reclamation's Salt Lake City, Provo, and Denver Offices are working with the Provo River Water Users Association, the Utah Division of Wildlife Resources, and the National Biological Survey to design monitoring programs for fish and aquatic invertebrates that will evaluate the biological benefits of the improved water quality. Additional data will be collected to determine airflow rates and aeration-caused power losses at operating points not tested in 1993 . . .