FIELD EXPERIENCES IN IMPROVING WATER QUALITY DOWNSTREAM FROM DAMS

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Abstract

Recent experiences by the Tennessee Valley Authority in improving water quality and fish habitat downstream from dams are presented.

At Douglas Dam, floating pumps near the surface of the large, thermally stratified reservoir are being used to move surface water, high in oxygen content, into low level hydroturbine intakes to increase the dissolved oxygen content of the turbine discharges.

Historically, the area near the mouth of the Little Tennessee served during the summer months as a cold water refuge for fish. The closure of Tellico Dam diverted the entire Little Tennessee flow via a canal into Fort Loudoun Reservoir for power generation through Fort Loudoun Dam turbines. This flow diversion eliminated the refuge. To reestablish the refuge, a siphon was installed to maintain a flow of cold water over Tellico Dam and an underwater rock barrier was constructed downstream to create a cool water pool.

At Upper Bear Creek, air was forced through diffuser pipes near the bottom of this relatively small, flow-through reservoir to oxygenate and precipitate iron and manganese before discharge through the dam.

Introduction

In recent decades, the Tennessee Valley Authority (TVA) has investigated numerous ways to improve releases from dams. These improvements are directed toward such things as addition of dissolved oxygen, changes in temperatures, reduction of mineral content, reduction of turbidity, etc.

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This paper presents three case studies, one involving dissolved oxygen improvement at Douglas Dam, another involving a temperature change at Tellico Dam, and a third involving iron/manganese reduction at Upper Bear Creek Dam.

Low Dissolved Oxygen Problem at Douglas Dam

Douglas Dam is located at mile 32.3 of the French Broad River in east Tennessee as indicated on the location map on Figure 1.

The dam is equipped with four hydroelectric generating units which discharge about 120 m^3/s (4,000 cfs) each. Low dissolved oxygen (DO) content in the discharges from Douglas Dam, attributed to thermal stratification of the reservoir, occurs annually. Discharge of this water is detrimental to aquatic life downstream and could contribute to waste assimilation problems.

Several methods of increasing the DO in the turbine discharges have been tested (Harshbarger, 1982, 1983, 1984) none of which have proven feasible from both a technical and economic viewpoint. Currently, TVA is testing the concept of using a high volume, low speed, axial pump to locally destratify the reservoir and move surface water into the turbine intake withdrawal zone. Professor J. E. Garton (retired), of Oklahoma State University developed the basic concept which has been applied by several others (Quintero and Garton, 1973; Strecker, 1976; Garton and Rice, 1976; Dortch and Wilhelms, 1978; Robinson, 1981), but has never been permanently installed in deep water, high flow situations.

A schematic of a "surface water pump" is shown on Figure 2. The Tennessee Valley Authority is currently testing three such pumps installed at Douglas Dam.

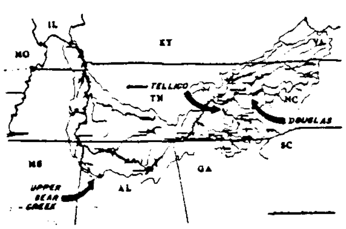

Figure 1. Location Map

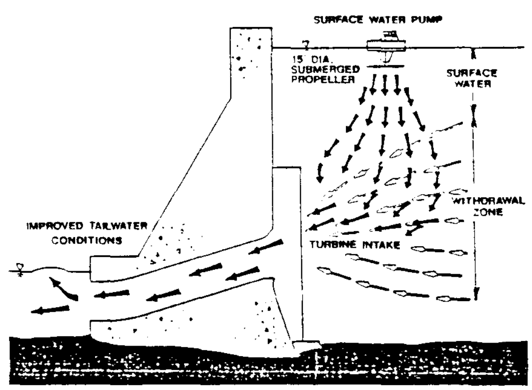

Figure 2. Schematic of Surface Pump Installation

Description of Equipment

Each of the three surface pumps being tested at Douglas Dam consists of a 6-bladed, 4.6-m (15-ft) diameter propeller connected by a shaft and gear box, to a 22 kW (30 hp) electric motor. The motor, gear box and controls are supported on a 4.9 m by 4.9 m (16 ft by 16 ft) square platform floating on the water surface just upstream from the turbine intake of Unit 4.

The propeller of each pump is suspended beneath the platform at a depth of about 3 m (10 ft). The propeller is turned at 21 rpm and moves approximately 1.4 m^3/s (500 cfs) of water down some 25 m (80 ft) to the turbine intakes. Electrical power for the pumps is supplied by a 100 amp line from the dam through control boxes mounted on the deck of the dam. Much of the machinery was purchased from Union Electric Company which had used the equipment for tests at Bagnell Dam on the Lake of the Ozarks in 1981 (Garton and Miller, 1982).

The platforms are held in position by cables and floating support legs attached to the face of the dam. The legs can be adjusted to position the centerline of the pumps as far as 50 feet from the face of the dam. In order to accommodate changes in the reservoir level, a short section of I-beam is attached to the end of each of the support legs. This I-beam slides up and down in a "C" shaped channel bolted to the face of the dam.

Tests and Results

Two of the pumps were installed late in the summer of 1986. By this time the reservoir had destratified and no conclusive tests could be run. However, preliminary tests using a dye tracer indicated that surface water could be forced down some 27 m (90 ft) and that nearly all of the flow from the pumps was entering the intake of turbine unit number four.

By June 1987, a strong temperature stratification had occurred in the reservoir and testing with all three pumps installed was begun. Low dissolved oxygen at the turbine intake levels does not usually occur until later in the year so evaluation of the pumps in their ultimate role of oxygenation devices was not fully accomplished by the June tests.

For the June 1987 tests, the three pumps were configured in a triangle arrangement with two pumps side-by-side parallel to and about 35 feet from the face of the dam and the third pump centered along-side and between the other two and the dam.

Figure 3 shows DO and temperature profiles in the reservoir on June 2, 1987. Top to bottom temperature difference was about 30°F. The DO profile shows a sag about 25 feet or so from the surface, but DO is still relatively high (6 mg/L) at the turbine intake level.

Figure 4 shows the change in temperature and DO measured in the scroll case of unit 4 during a 45-minute period when the pumps were operated. These data indicate that pump operation forced enough surface water into the turbine intake to increase the scroll case water temperature about 2°C and the DO about 1 mg/L.

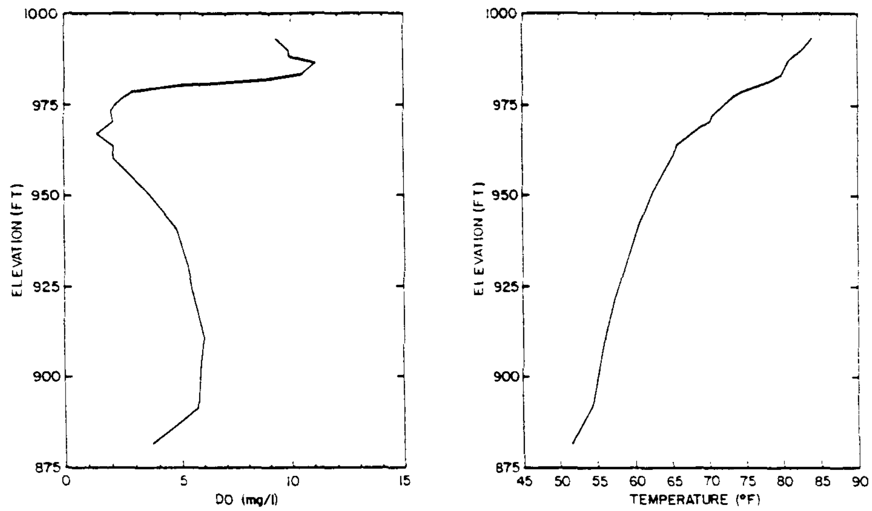

Figure 3. Temperature and DO Profiles in Douglas Reservoir, June 2, 1987

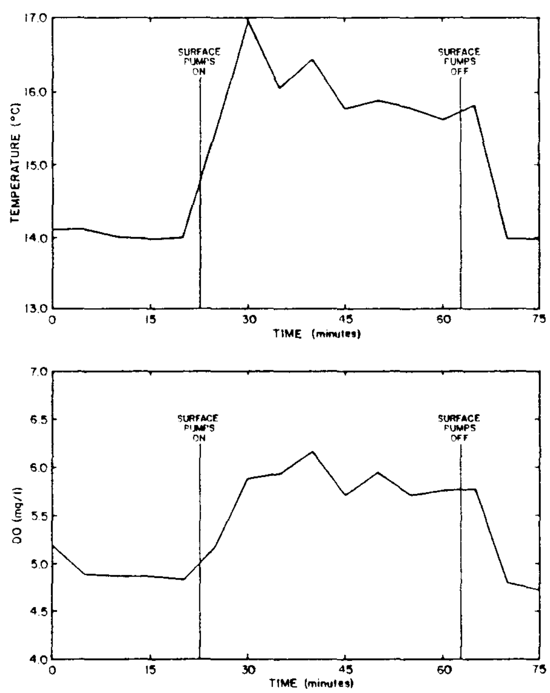

Figure 4. Effect of Surface Pump Operation on Temperature and Dissolved Oxygen in Douglas Unit 4 Scrollcase, June 2, 1987

So far the results from preliminary tests are inconclusive. Tests to evaluate the method are planned to continue throughout the summer of 1987. These tests include measurements to define the pump plume shape and penetration; long-term temperature and DO measurements to investigate the stability of the flow patterns established by the pumps; and repositioning the pumps to investigate the effect of location and grouping.

Water Temperature Problem at Tellico Dam

Tellico Dam is located at mile one on the Little Tennessee River as indicated on Figure 1. The dam has no power facilities, but serves to divert the flow of the Little Tennessee through a canal into Fort Loudoun Reservoir. The only discharge facilities at Tellico Dam are overflow spillways to be used during flood conditions. Prior to the construction of Tellico Dam, the mouth of the Little Tennessee River served, during the summer months, as a cold water refuge for fish. The completion of Tellico Dam eliminated this region of cold water. To recreate this refuge, two actions have been taken by TVA: (1) A siphon has been installed to pull cold lake water over Tellico Dam during the summer months; (2) An underwater barrier has been erected just upstream from the mouth of the Little Tennessee to catch this cold water and create a pool.

Siphon

The siphon, shown on Figure 5, consists of a 40-foot length of 12-inch diameter rubber hose which extends below the thermocline on the upstream side of the dam, 12-inch diameter piping which carries the water over the spillway gate, a 12-inch air operated butterfly valve for off-on flow control, and a short length of discharge pipe.

The entire apparatus is mounted on and supported by the center gate of the three spillway gates at the dam. The mounting is such that the gate can be raised or lowered without interference from the siphon. Flow is initiated in the spring using a portable vacuum pump and is continued through the period when the Tellico reservoir is temperature stratified. Flow through the siphon has been measured to be about 8 cfs.

Underwater Barrier

During 1986, a small underwater barrier was constructed near the mouth of the Little Tennessee at the location shown on Figure 6. The purpose of this barrier was to contain the cold water supplied by the siphon and thus create a cool water pool. The barrier was constructed near the edge of a deep pool across a relatively narrow channel near the stream mouth.

The barrier was constructed of 6- to 8-inch diameter stone hauled to the site on barges and dumped into place. To seal the barrier, the upstream side was covered with an impervious plastic membrane held in place with sandbags. The finished barrier was about 6 feet high and 150 feet long. The top of the barrier was maintained at 16 feet below the lowest water levels expected so as not to interfere with navigation. Sketches of the constructed barrier are included on Figure 6.

The siphon was operated during the summer of 1985. The barrier was completed in late spring of 1986 and the siphon was operated from late spring to early fall of 1986. Preliminary indications are

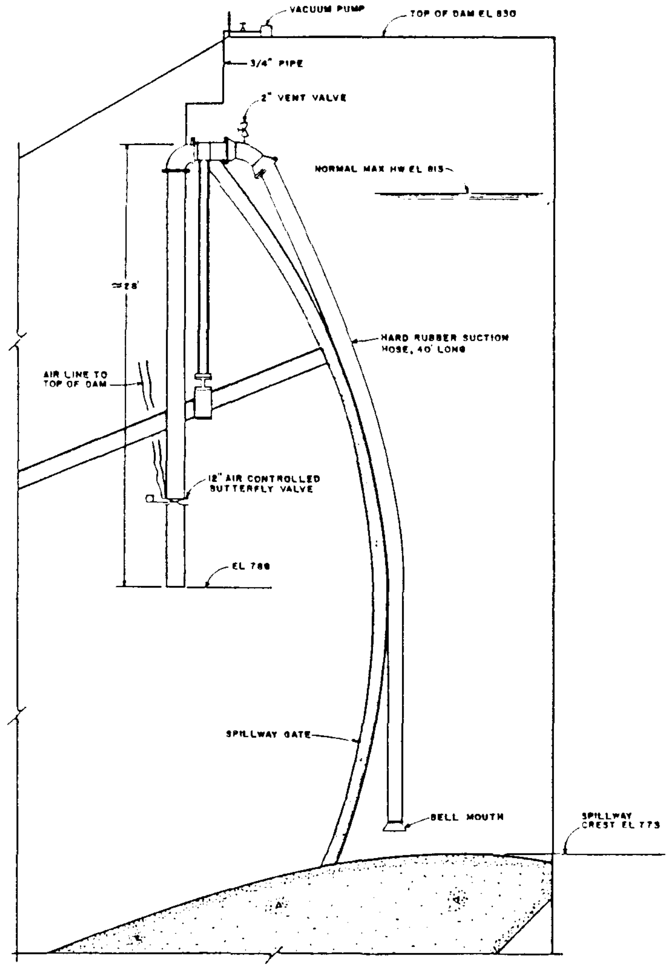

Figure 5. Sketch of Siphon Over Tellico Dam

that fish are using the refuge. The siphon will again be operated in 1987 and plans are to obtain reliable data to verify the usefulness of the siphon-barrier system.

Dissolved Metals Problem at Upper Bear Creek Dam

Upper Bear Creek Dam is an earth-fill structure situated on Bear Creek in northwest Alabama as shown on Figure 1. The purpose of the dam is for fish and wildlife, recreation and water supply.

A water treatment plant which obtains raw water from the reservoir often struggles with the removal of the iron and manganese. In addition, water released through an aerating valve does not provide sufficient oxidation time for the dissolved iron and manganese, which oxidize and precipitate downstream from the dam staining the area and coating much of the substrate. When conditions are dry, very small releases are made through an unaerated valve. The result is not only iron and manganese

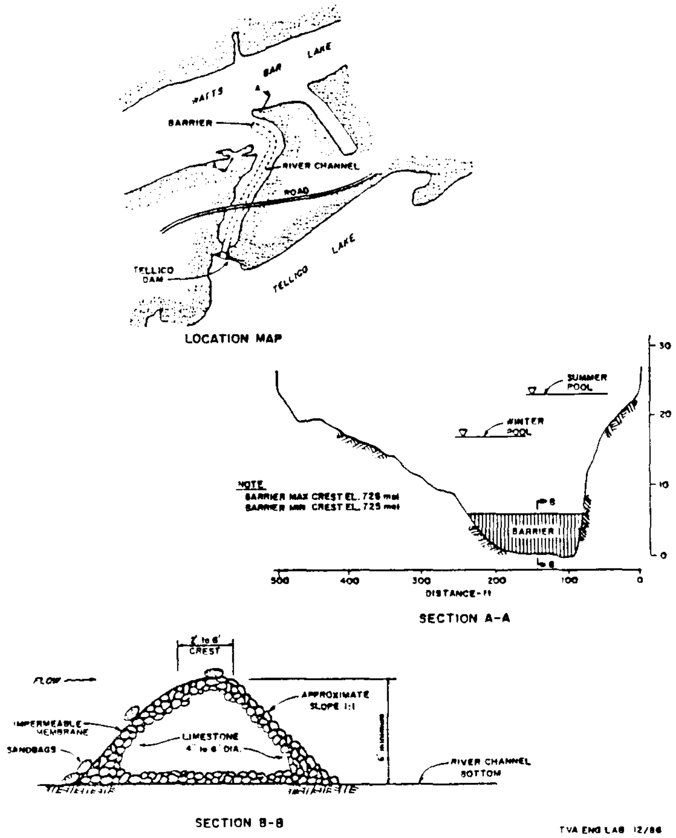

Figure 6. Underwater Barrier for Tellico Tailrace Fish Refuge

problems, but concentrations of hydrogen sulfide as high as 0.5 mg/L occur in the stream. Hydrogen sulfide concentrations greater than 0.002 mg/L can be toxic to aquatic life.

Design and Installation of Aeration System

In early summer, the reservoir becomes thermally stratified and anoxic conditions develop in the hypolimnion and iron and manganese in the reservoir sediments dissolve and enter the water column. The basic methodology investigated was to inject air near the bottom of the reservoir so that the rising bubbles would cause mixing of the epilimnion and hypolimnion as well as supply oxygen to the water.

PVC pipes 3 inches in diameter with 1-mm diameter holes every 12 inches were used as diffusers to inject the air. To keep the diffusers from being submerged in sediments on the bottom of the reservoir, they were attached to aluminum support frames which positioned them some three feet above the reservoir floor.

The locations of four sites selected to inject air through 40-foot long diffusers into the main flow path just upstream from the dam are shown on Figure 7. The diffusers were placed in the original stream bed where the depth of the reservoir is about seventy feet. The stream bed at the chosen sites is forty to fifty feet wide and the banks are relatively steep.

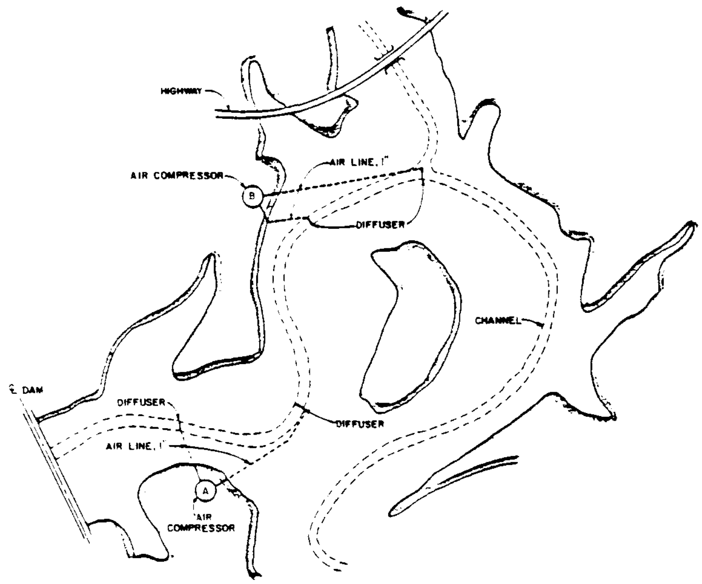

Figure 7. Location of Diffuser Sites at Upper Bear Creek

Air was supplied to the diffusers by two electrically powered compressors each supplying 28 cfm of air at 125 psi through 1-in. diameter hose to each of two diffuser. Flowrate to each diffuser was metered using a rotameter and controlled by a gate valve near the compressor outlet.

Operation of the completed system began in March 1987. Dissolved oxygen and temperature profiles for mid-May in 1985, 1986, and 1987 are compared in Figure 8. These data indicate that the aeration of the reservoir in 1987 has resulted in significant increases in dissolved oxygen as compared to the previous two years, especially near the bottom of the reservoir. The deeper portion of the reservoir was significantly warmer in 1987 than in the previous two years indicating that the reservoir was mixed by the aeration system. Figure 9 shows data indicating that the pH increases in the direction of the dam. This increase is probably due to the scrubbing of the carbon dioxide in the water column and is important because iron and manganese are more readily oxidized at higher pH.

Iron/manganese concentrations observed in 1987 are shown on Figure 10. It remains to be seen if the aeration system will be successful in preventing the much higher concentrations of iron and manganese like those observed in late summer of past years when concentrations of dissolved iron and manganese reached as high as 11

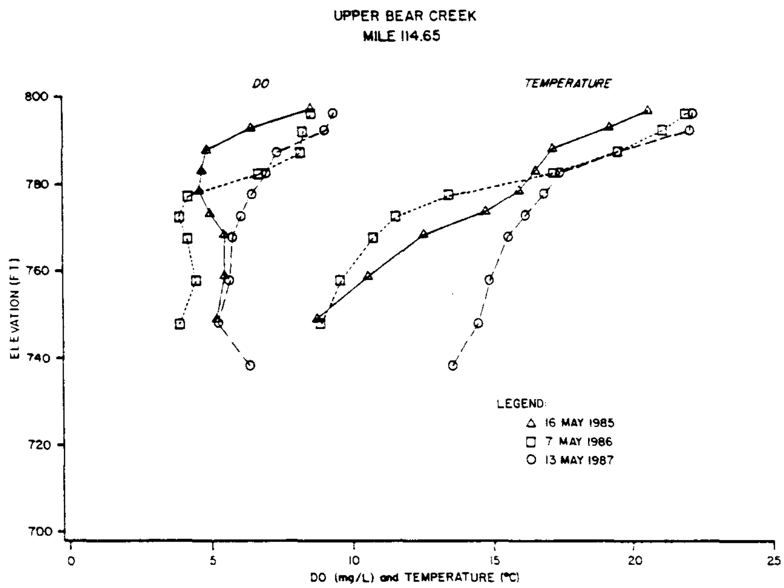

Figure 8. Dissolved Oxygen and Temperature Profiles in Upper Bear Creek

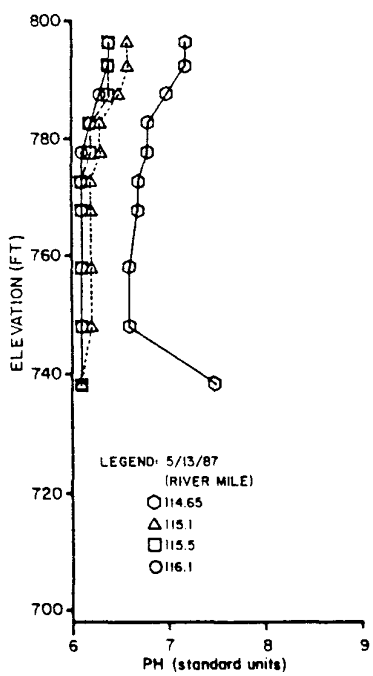

Figure 9. Measured pH Values in Upper Bear Creek

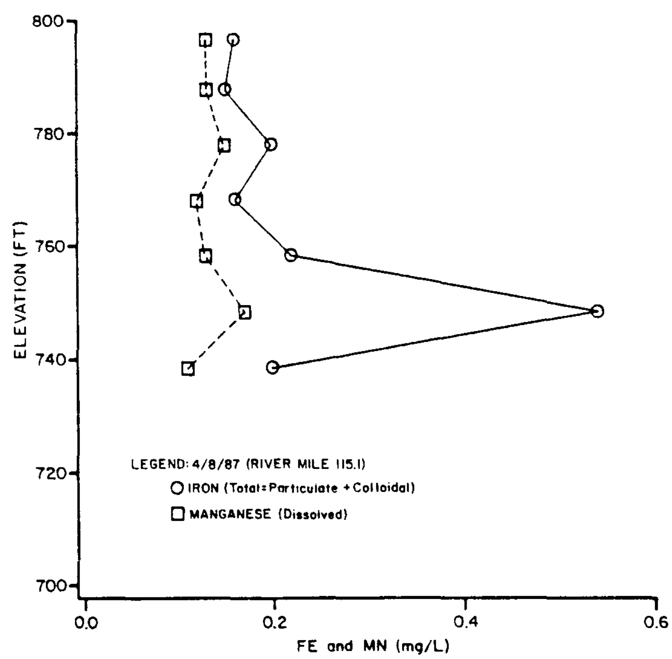

Figure 10. Observed Iron and Manganese Concentrations in Upper Bear Creek

and 5 mg/L, respectively, in the reservoir. However, even if the the iron and manganese concentrations reach the levels seen in previous years, it is still possible that the iron and manganese will be in the oxidized rather than the dissolved forms. Release of oxidized iron and manganese would at least confine the precipitates to the more immediate tailrace area rather than extend their occurrence farther downstream.

Indications are that the aeration system is able to oxidize the iron, but most of the manganese observed through May still remains dissolved. The oxidation of manganese is believed to be facilitated by microorganisms (Gordon, 1983) and it remains to be seen whether the right combination of microorganisms, pH, and dissolved oxygen are provided.

Appendix 1--References

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