A Reservoir Oxygenation System to Meet Re-licensing Water Quality Goals at Shepaug Dam

Mark Mobley, Mobley Engineering, Inc.
Rich Szatkowski, FirstLight Power Resources

ABSTRACT

Deep reservoirs often thermally stratify during the summer months due to warm temperatures and solar input at the water surface. With sufficient storage time and oxygen demands in the reservoir, dissolved oxygen levels at the level of a hydropower intake can be well below state water quality standards. At Shepaug Dam, on Lake Lillinonah near Danbury Connecticut, Northeast Generation Services was facing re-licensing requirements that included increased dissolved oxygen levels in the project releases into the Housatonic River. After reviewing available dissolved oxygen enhancement alternatives, Northeast Generation Services chose a reservoir oxygen diffuser system to provide the necessary release improvements and initiated efforts to obtain the necessary permits, state and FERC approvals. In the mean time, when the hydropower release was less than 5 mg/L, an effort was made to increase tailrace dissolved oxygen by spilling water through a taintor gate. In 2006, the oxygen diffuser system was installed and operated to maintain dissolved oxygen levels in the releases. In 2007, the system will be operated to maintain requirements specified in the FERC license. This paper will describe the installation and initial operation of the oxygenation system.

INTRODUCTION

Lake Lillinonah was formed by the construction of the Shepaug Hydroelectric Project on the Housatonic River near Danbury, Connecticut in 1955. It has a drainage area of about 1,400 square miles and a total volume of 74,000 acre feet. At the full pond elevation of 200 feet the reservoir has a surface area of 1,870 acres and is approximately 12 miles long. During normal operations the reservoir elevation fluctuates about 4.5 feet. Lake Lillinonah is operated as a multiple use impoundment. Hydro facilities at the project include a 1,400 foot long concrete gravity structure dam with a crest elevation of 206 feet, and a single unit powerhouse shown in **Figure 1**.

Figure 1: Shepaug Dam Powerhouse and Oxygen Supply Facility

The project is remotely operated from the Rocky River control room. The fixed blade turbine runner was installed in 1984 as a replacement to the original Kaplan runner, with a maximum capacity rating of 43 MW. The project was operated by the Connecticut Light and Power Company, (CL&P) 1955 to 2001, Northeast Generation Services (NGS) 2001 to 2006 and is currently operated by FirstLight Power Resources (FirstLight). The project is operated under FERC License number 2576-022.

Dissolved oxygen (DO) levels in the releases from Shepaug dam (**Figure 2**) were identified as a concern early on during efforts toward re-licensing the project. DO levels varied widely during each season depending on weather and water flow conditions. The terms of the Connecticut Department of Environmental Protection Clean Water Act Section 401 water quality certificate that was part of the FERC license application specifically called for the installation of a reservoir oxygenation system to improve DO levels in the releases, with the system to be operated to meet regulatory requirements of 5 mg/L within three years after issuance of the project license. The new FERC license was issued in 2004. The oxygenation system was installed in 2006 in order to gain one season of operating experience before meeting regulatory requirements.

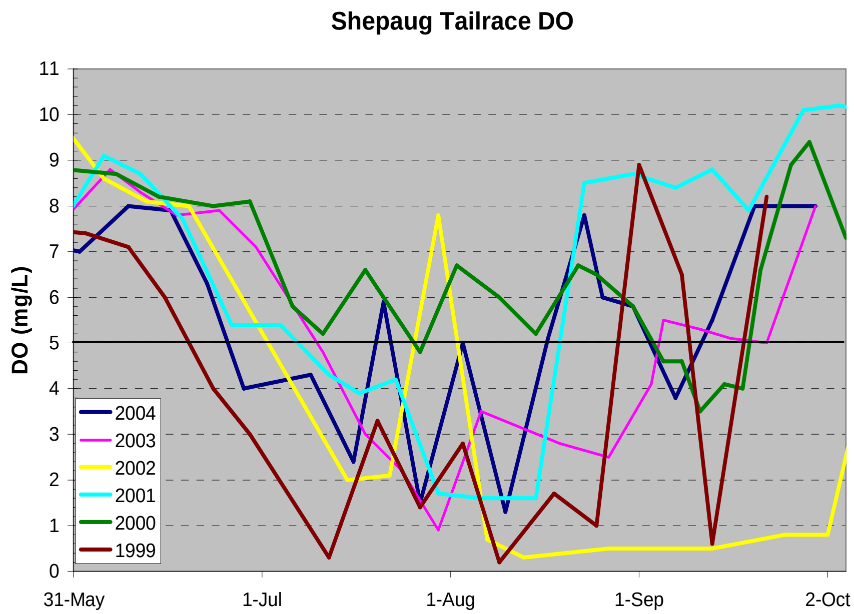

Figure 2: Historical Shepaug DO Levels from Shepaug Dam

ITERIM AERATION PROCEDURES

In an attempt to avoid release DO levels of less than 5 mg/L, NGS voluntarily initiated a procedure to spill up to 20% of the turbine flow through a project taintor gate when conditions warranted. The water flow released from the taintor gates is from high in the reservoir and is generally high in DO content. In addition, the spill release is aerated by the violent splashing action of release over the spillway (**Figure 3**). The water released by spilling therefore had a good DO content that mixed with the turbine releases to obtain improved DO levels downstream of the project.

Figure 3: Spilling Procedures at Shepaug Dam

The spilling procedure was successful at increasing downstream DO levels but would not meet the 5mg/L standard when the pond was severely stratified. Also, significant generation revenues were lost when spilling water.

DO ENHANCEMENT STUDIES AND WATER QUALITY MONITORING

Several studies were undertaken at Shepaug Dam by engineering firms evaluating potential aeration options (1987, 1988) and by the Connecticut Department of Environmental Protection (CDEP) and Northeast Utilities documenting water quality conditions (1988, 1995). In 1998, CL&P invited the Tennessee Valley Authority (TVA) to assist with evaluation of seventeen potential aeration options at Shepaug. TVA had recently completed DO and minimum flow improvements at sixteen hydro projects in the Tennessee Valley under the 1992 TVA Lake Improvement Plan. During this program, TVA gained up-to-date experience and had developed or improved several new aeration methodologies. In March of 1998, CL&P conducted an onsite stakeholder meeting with a team of experts from TVA, and representatives from CDEP, Housatonic Valley Association and the U.S. Fish and Wildlife Service. TVA prepared a report that included preliminary evaluation of the 17 aeration options and a recommendation for a feasibility study of reservoir oxygenation and three other alternatives. Based on subsequent evaluations, CL&P selected reservoir oxygenation for further design study and potential application to Shepaug. In 1999, TVA provided CL&P with a conceptual design report for the Shepaug Oxygen Diffuser System that included hydrodynamic modeling results, reservoir oxygen demand and capacity evaluations, cost estimates, a recommended diffuser layout and oxygen supply facility size. TVA was well positioned to provide such a study with seven oxygenation systems in operation at TVA projects for several years. CL&P utilized these reports and others in preparation of their FERC license application.

CL&P and then Northeast Generation Services (NGS) conducted an extensive monitoring program to obtain water quality data as requested by the CDEP and to verify DO enhancement system design parameters. The release DO and temperature were monitored at the Shepaug tailrace with a DO probe that was incorporated into the plant SCADA system.

RESERVOIR OXYGENATION SYSTEM FACILITIES

The reservoir oxygenation system facilities at Shepaug Dam include an oxygen supply facility where liquid oxygen is delivered by truck and stored, a flow control system, supply piping and the diffuser system in the reservoir. After additional studies, NGS chose an average oxygen delivery capacity of 40 tons per day to with additional capacity of up to 90 tons per day to provide sufficient oxygenation for short term peak water flow and unusually high oxygen demand events. All systems and piping at Shepaug are designed to meet the peak oxygen delivery capacity requirements. The system will be operated as needed from June to October each year during the period the reservoir is thermally stratified.

Oxygen Supply Facility

The oxygen supply facility at Shepaug Dam, shown in **Figure 4**, is located on the edge of a large asphalt parking lot near the powerhouse downstream of the dam. The facility includes an oxygen storage tank, ambient air vaporizers, pressure control and flow distribution piping. The

13,000 gallon oxygen storage tank is essentially a large thermos bottle that is insulated well enough to maintain oxygen in its liquid state at -300°F for several weeks. A bulk gas supplier, BOC Gases, a member of the Linde Group, was contracted to provide the cryogenic equipment and flow control manifold and supply oxygen to the system. BOC monitors tank levels and delivers oxygen in liquid form via trucks to the tank during the operating season as needed. To convert the liquid oxygen to its gaseous state, ambient air vaporizers are used to warm the oxygen flow out of the tank up to ambient temperatures. A pressure control station provides a set supply pressure to the oxygen distribution piping. A flow control manifold controls the oxygen flow to each diffuser and is tied to plant operations with operator settings to provide different flow rates of oxygen with and without turbine operation. The flow control manifold includes individual flow rate and pressure measurements for each diffuser line and is controlled through the plant SCADA system. Stainless steel supply piping, 2 inches in diameter, runs from the flow control manifold up and over the dam to the reservoir to supply each of the three diffusers. Trucks deliver oxygen to the system an average of once every few days but could reach two to three trucks per day under maximum use conditions.

Figure 4: Shepaug Oxygen Supply Facility

Reservoir Diffuser System:

The reservoir diffuser system for Shepaug was designed and installed by Mobley Engineering, Inc. (MEI) based on a design previously developed at the Tennessee Valley Authority (TVA) that is currently installed and operated at ten TVA reservoirs and eleven reservoirs for other utilities. MEI designed the diffuser system for Shepaug utilizing experience gained at TVA and six recent diffuser installations in water supply and hydropower reservoirs. The line diffuser is a simple and economical design that spreads bubbles over a large area and is installed and retrieved for any required maintenance without divers. The system uses long lines of flexible porous hose to avoid clogging and other maintenance problems experienced by previous designs that used ceramic diffusers. The diffuser is a two pipe system as shown in **Figure 5** that includes a high density polyethylene (HDPE) supply pipe to distribute the gas along the length of the diffuser and buoyancy pipe that can support the entire weight of the diffuser system when filled with air. Flow control orifices control the oxygen flow to independent lengths of porous hose to maintain a continuous flow of small gas bubble along the full length of the diffuser. Concrete anchors are attached to the diffuser piping with stainless steel cable and saddle connections. The line diffuser has proven to be an efficient and economical aeration diffuser design that transfers oxygen efficiently, and minimizes temperature destratification and sediment disruption.

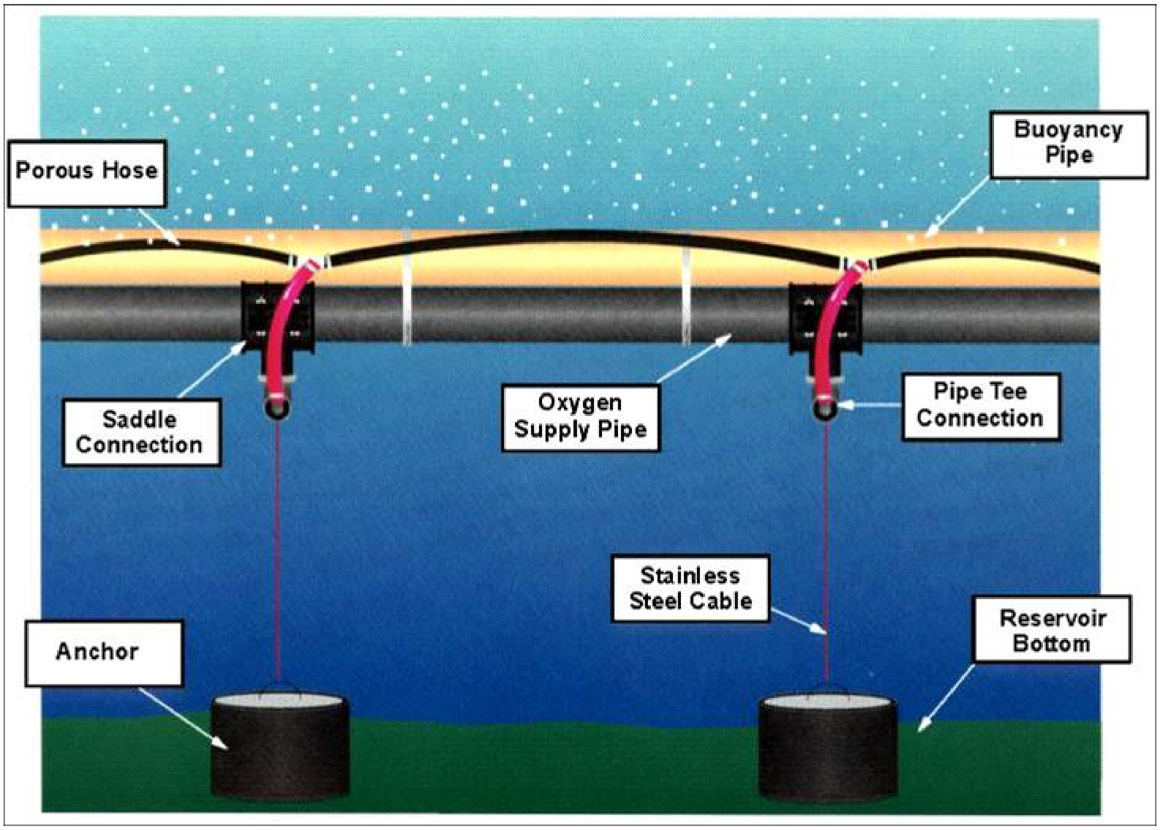

Figure 5: Diffuser Details

For Shepaug, a diffuser layout was developed that placed three diffusers in the old riverbed in the forebay extending almost 4,000 feet upstream of the dam as shown in **Figure 6**. The diffusers were placed in the deepest areas of the forebay to achieve maximum oxygen transfer efficiency but elevated 10 feet off the reservoir bottom with appropriate anchor cable lengths to avoid any potential of disrupting bottom sediments. By extending the oxygen placement far upstream of the dam a volume of oxygenated water can be maintained to be available for the next hydropower operation.

The diffuser lines at Shepaug were installed working from a boat ramp at the north abutment of the dam. Each line was assembled on shore and floated in front of the dam behind the no boat buoy line until the entire length was completed. Anchors were attached to the diffusers in the water. Each diffuser pipe was connected to the stainless steel supply pipes routed over the dam and pulled into position over the deployment location using boats, fixed anchor points and ropes. The buoyancy pipe was then filled with water from the connection on the top of the dam to sink the diffuser into place in a controlled manner.

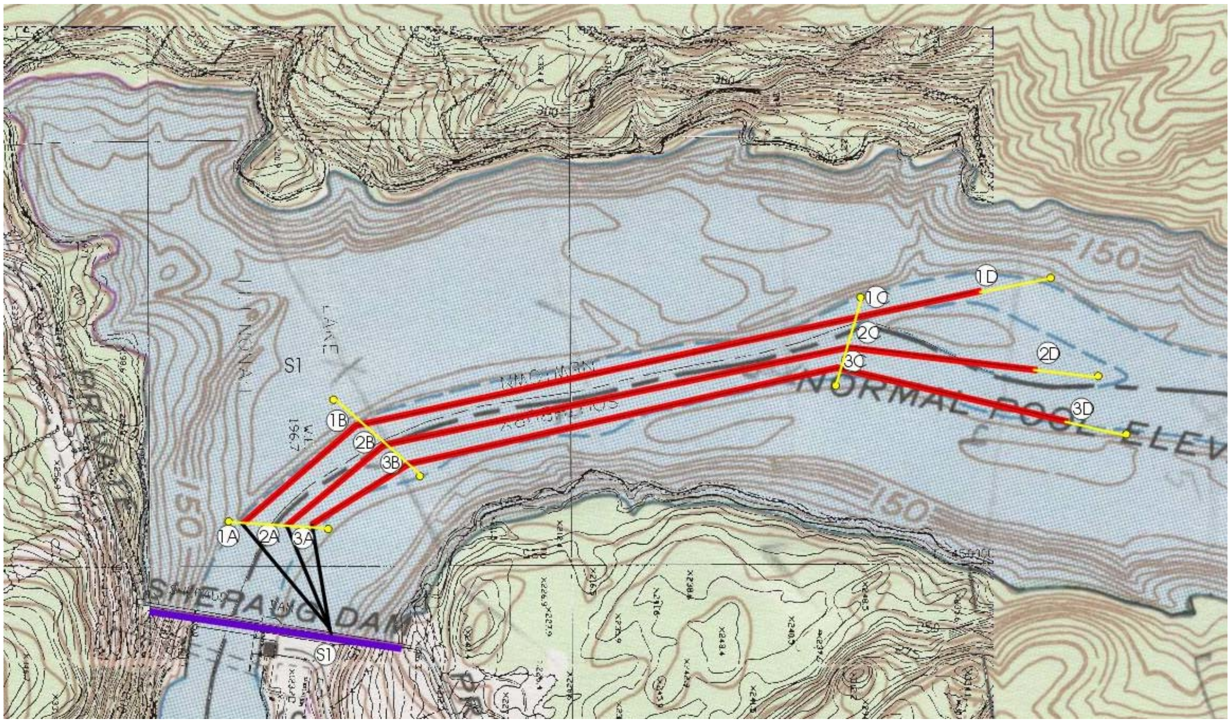

Figure 6: Reservoir Diffuser Layout at Shepaug

INITIAL OPERATION AND RESULTS

DO levels in the releases from Shepaug had fallen to 5 mg/L in mid-July compelling NGS to initiate spilling procedures as the oxygen supply facility was being completed and first diffuser line was being assembled. On July 25th, the first diffuser line was deployed in the reservoir. The oxygenation system was placed in operation over the next two days and spill operations were discontinued on the 27th. DO levels were maintained with only one diffuser line in operation for about one week and then with additional diffusers as they were deployed. Operation of the system resulted in only a few short excursions below 5 mg/L as shown in **Figure 7**. Two flow rate settings were placed in operation; an “on-line” flow rate setting for when the hydro turbine is in operation (typically 10,000 to 60,000 scfh), and an “off-line” flow rate setting for the rest of the day (typically 1,000 to 10,000 scfh). The on-line setting was calculated to increase the turbine flow by a desired dissolved oxygen amount. The off-line setting was calculated to maintain the DO level of the oxygenated volume of the forebay. Oxygen flow rate settings were increased as incoming DO levels fell during the summer season. In fact, DO levels in the forebay were dramatically increased due to operation of the oxygenation system as shown in **Figure 8**. During the dry month of August, hydropower operations were reduced to only a few hours per day. During this time, the initial operation of the turbine resulted in a short period of low DO measurements. With only a few hours of generation, there were long periods of operation at the off-line flow setting that delivers a continuous small flow rate of oxygen to the reservoir. Due to the efficiency of the line diffuser design, a small oxygen flow rate tends to be delivered at an elevation in the reservoir not far above the diffusers. The long periods of small flows may have distributed most of the oxygen near the bottom of the reservoir instead of higher in the reservoir where low DO levels are evident such as at elevation 165 feet on August 23rd in **Figure 8**. This low DO layer may have contributed to the period of low DO with initial turbine operation.

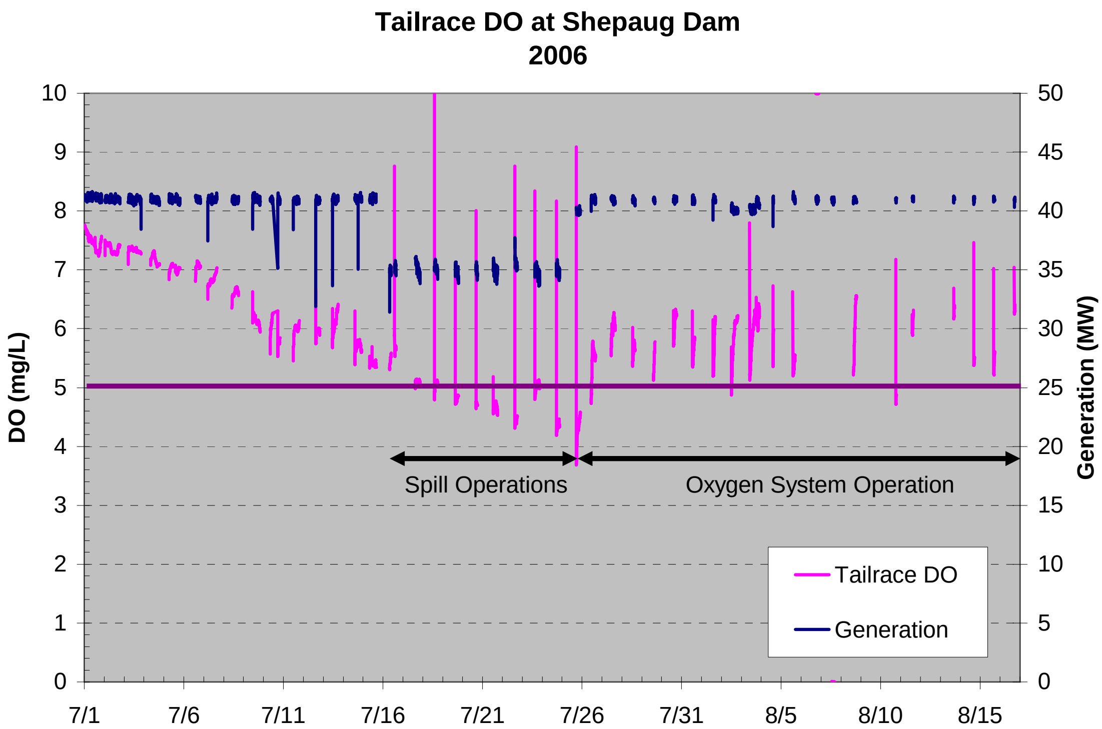

Figure 7: DO Enhancement Results at Shepaug, 2006

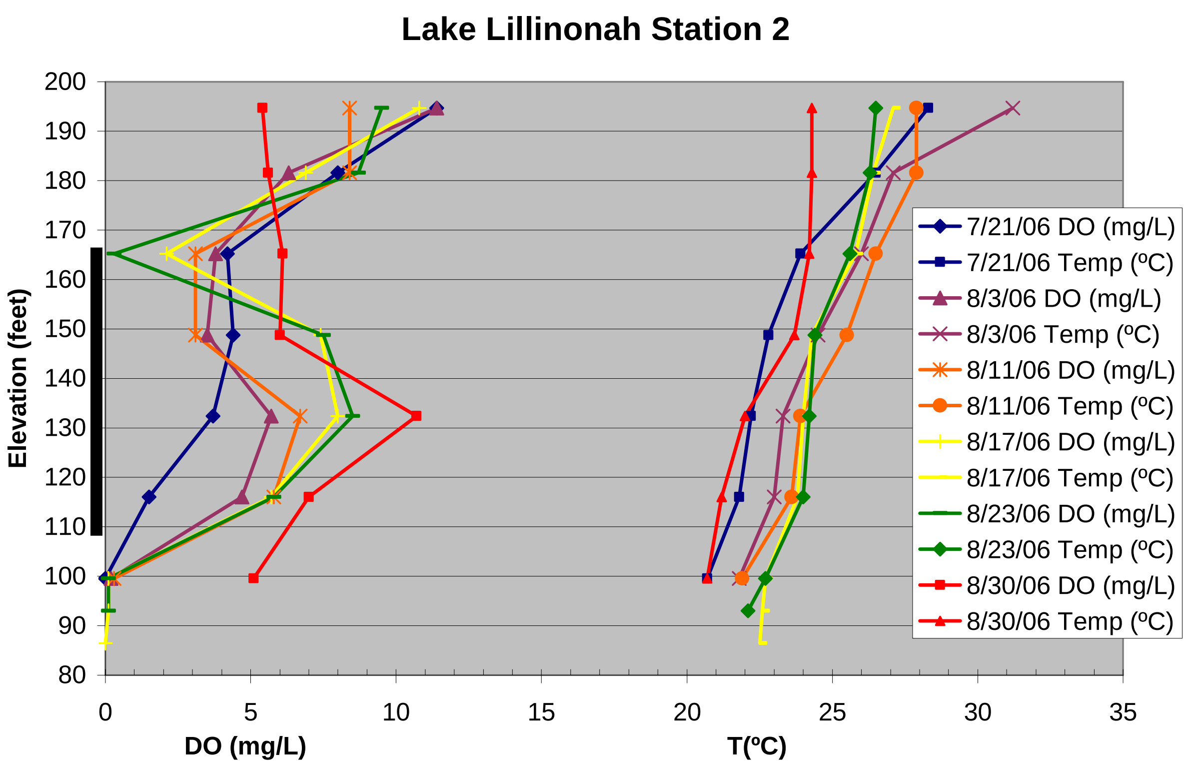

Figure 8: Water Quality Profiles Upstream of Shepaug Dam during Operation of the Oxygenation System

After initial turbine operation, DO levels increased by as much as 1 mg/L and leveled out over time as shown in **Figure 9**. Oxygen flow settings were adjusted to keep even the initial low DO event above 5 mg/L as much as possible.

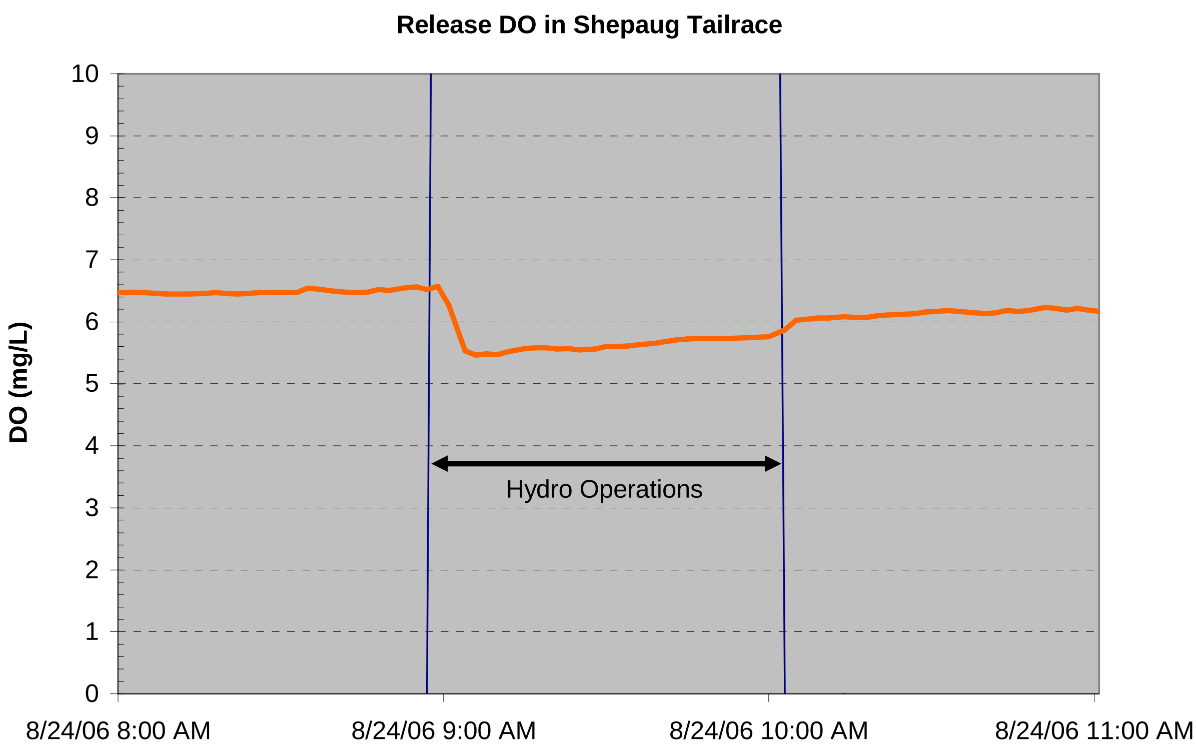

Figure 9: Low DO Upon Initial Turbine Operation 8/24/06

CONCLUSIONS AND FUTURE PLANS

The oxygenation system at Shepaug has successfully demonstrated the capability to increase dissolved oxygen levels in the hydropower releases allowing FirstLight to meet downstream water quality standards without spilling. Installation of the system was completed within budget and on schedule. The system will continue to be operated to meet state DO regulatory standards of 5 mg/L in the Housatonic River and as a part of the FERC license requirements for the project. Downstream DO levels will continue to monitored and reported to the Connecticut Department of Environmental Protection. Water samples and profiles will continue to be collected in the reservoir. A new off-line operating setting will be utilized to place oxygen higher in the water column during no generation periods in an attempt to reduce or eliminate the short period of low DO water seen in 2006 upon initial operation of the turbine.

AUTHORS

Mark Mobley, P.E., Mobley Engineering, Inc.
Mark Mobley is a Mechanical Engineer with over 16 years of experience working for the Tennessee Valley Authority Engineering Laboratory as part of a team to develop and apply DO enhancement technologies. In 1999 he founded Mobley Engineering, Inc. to offer design and installation of reservoir oxygen diffuser systems for hydropower and water supply reservoirs.

Rich Szatkowski, P.E., FirstLight Power Resources
Rich Szatkowski is a Senior Engineer with FirstLight Power Resources with over 25 years experience. He is responsible for upgrading and automating hydro plant equipment.