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TVA Reservoir Aeration Diffuser System

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Abstract

The Tennessee Valley Authority (TVA) has developed an efficient and economical aeration diffuser design that has been installed and operated successfully at six TVA hydropower projects, one TVA nuclear plant and two non-power reservoirs. The line diffuser design transfers oxygen efficiently, and minimizes temperature destratification and sediment disruption by spreading the gas bubbles over a very large area in the reservoir. TVA test results have consistently indicated oxygen transfer efficiencies of 90 to 95 percent. The line diffusers are installed from the surface and can be retrieved if necessary for maintenance without the use of divers. The diffusers can be supplied with air or with oxygen, either from a bulk liquid oxygen storage tank, an onsite air separation plant, or air compressors. A line diffuser system can be designed to continuously aerate a large volume in the reservoir to handle peaking hydroturbine flows. Aeration within the reservoir can be an economical means to meet dissolved oxygen requirements for hydropower releases.

Introduction

The dissolved oxygen content of reservoir releases has become a problem for hydropower projects. Many FERC licenses now include minimum dissolved oxygen requirements. TVA has just completed the Lake Improvement Plan, a five-year, voluntary program that included developing and installing equipment to meet target levels of dissolved oxygen and minimum flow at 16 TVA hydropower projects. TVA now maintains target levels of dissolved oxygen and minimum flow at all of its 28 hydropower projects. Several new and innovative aeration alternatives were developed and applied over the course of the Lake Improvement program. Many different aeration alternatives were applied at the 16 TVA projects that required dissolved oxygen improvements. Each hydropower project was

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evaluated for site-specific requirements and the best alternative or combination of alternatives was applied. The TVA program included eight applications of turbine venting, six of forebay oxygen diffusers, two of surface water pumps, two of air blowers, two of aerating weirs, one of penstock oxygen diffusion, and one application of auto venting replacement turbines. Several projects required combinations of up to three alternatives to meet target aeration requirements.

Aeration within the reservoir can be an economical means to meet dissolved oxygen requirements for hydropower releases, even though oxygen costs may be high. Other aeration alternatives may not be applicable at a specific hydropower site or may be insufficient to meet dissolved oxygen requirements. Aeration within the reservoir can accomplish dissolved oxygen requirements without causing adverse effects on turbine generation, destratification in the reservoir, or significant increases of temperature or total dissolved gas in the release that may be associated with other aeration methods. Reservoir aeration is also well-suited for use as a topping off system that complements the use of other less expensive aeration alternatives that do not meet dissolved oxygen requirements alone. Oxygen costs have remained relatively stable for the past decade with a growing demand and supply for atmospheric gases. Reservoir aeration can provide a high oxygen transfer to minimize operational costs and can be located to optimize the aeration of the water being released through the hydropower project. Aeration in the reservoir also has the potential to eliminate hydrogen sulfide, iron, and manganese in the reservoir hypolimnion to improve water quality in the reservoir and in the releases.

Description of Diffuser Aeration System

Reservoir aeration diffuser systems consist of an oxygen or air supply facility, supply piping, and diffusers as shown in Figure 1. The diffusers are located near the bottom of the reservoir as shown in Figure 2.

Air or Oxygen Supply

Reservoir aeration diffusers can be supplied with either air from compressors, or oxygen from a liquid oxygen storage tank or pressure swing adsorption facility (PSA). Each source of gas supply has its own limitations and costs. The diffusion of air into the reservoir requires five times the total diffuser capacity as oxygen and is often limited by the supersaturation of gases in the tailrace when the water is suddenly returned to atmospheric pressure. Liquid oxygen is expensive and requires dependence on a contracted vendor for reliable delivery and future pricing. A pressure swing adsorption system separates oxygen from a compressed air stream to provide 90 percent pure oxygen to the diffusers, but requires a substantial capital investment that is difficult to justify with the seasonal operation typically associated with hydropower aeration requirements.

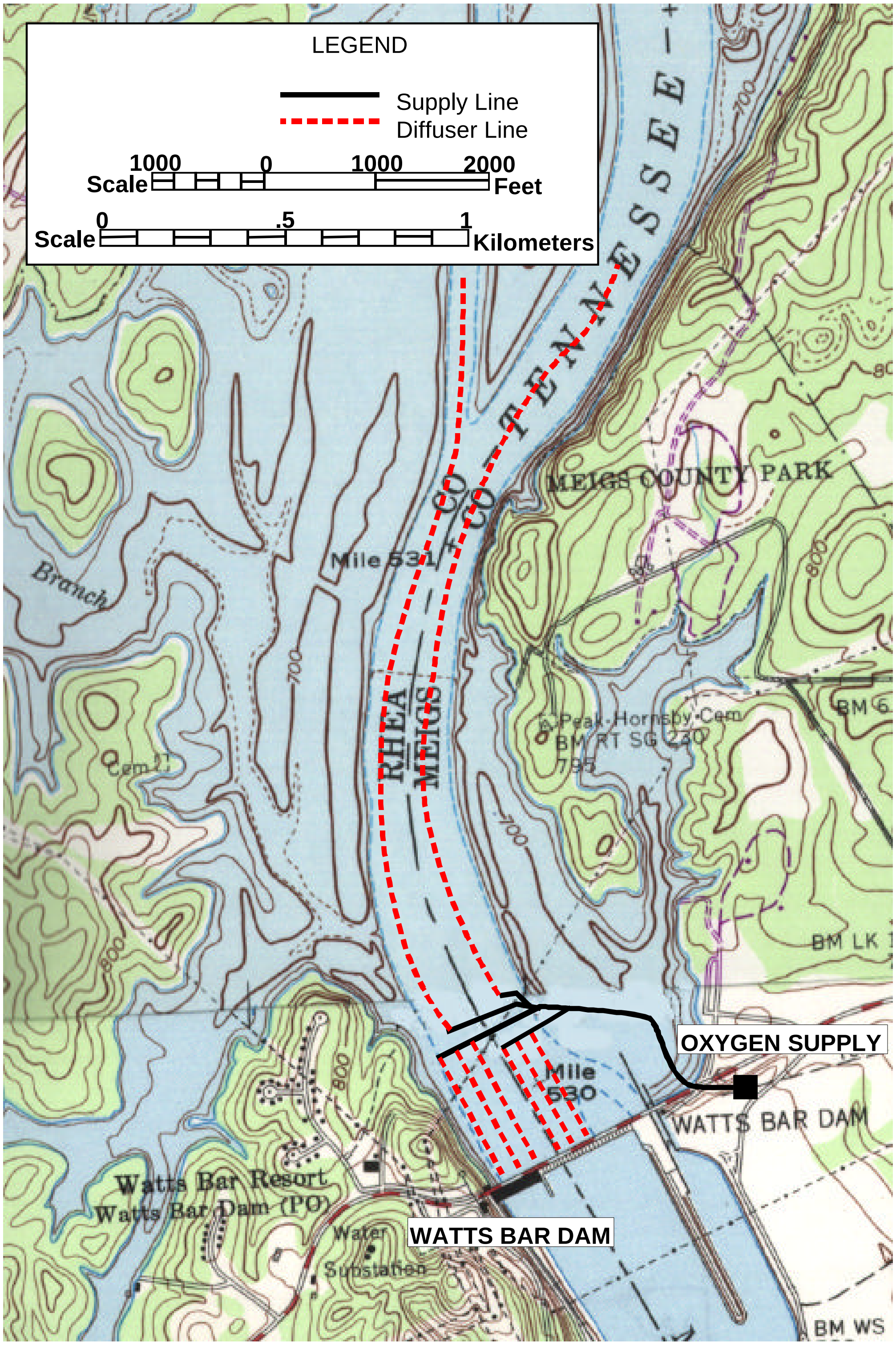


Figure 1. Line Diffuser Layout At Watts Bar Dam

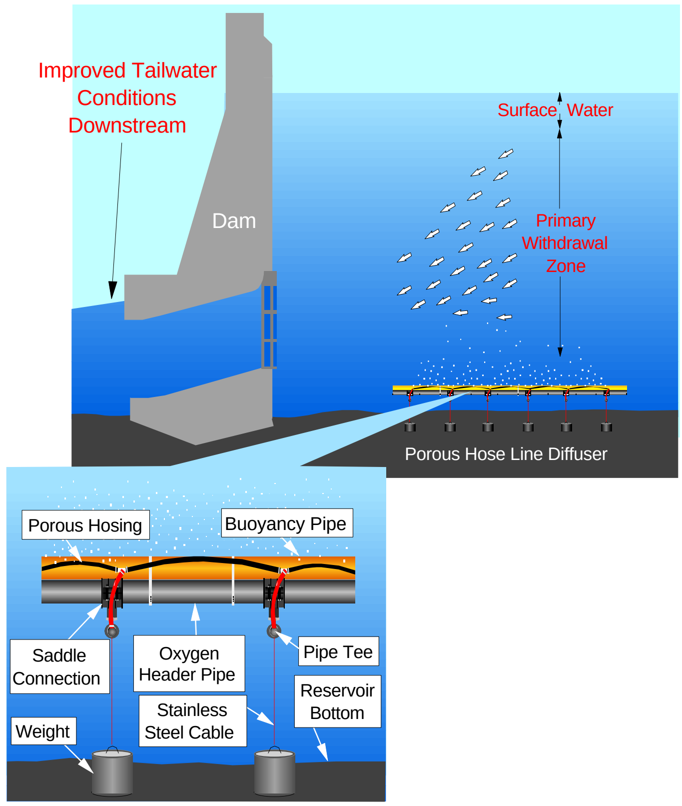


Figure 2. Line Diffuser Design

Line Diffuser Design and Installation

The TVA line diffuser is designed to minimize costs no matter which gas supply is chosen. Operational costs are minimized due to high oxygen transfer efficiencies, flexibility of operation, and infrequent maintenance. Installation costs are minimized by strategic handling of peaking flows and innovative use of readily available, low cost materials.

The TVA line diffuser has demonstrated high oxygen transfer efficiency to minimize oxygen costs for system operation. The line diffuser design achieves high oxygen transfer by spreading the oxygen bubbles over long, widely separated lines that are near the reservoir bottom. Location of the diffuser deep in the reservoir provides a strong oxygen transfer driving force and long bubble contact times for efficient oxygen transfer. Distribution of the oxygen bubbles over a very large area avoids localized dissolved oxygen build-up and prevents reservoir destratification. TVA line diffuser installations have achieved oxygen transfer efficiencies of better than 90 percent and have little effect on the thermal stratification of the reservoir.

The TVA line diffuser design provides flexibility to meet the changing dissolved oxygen demands of hydropower operation. Gas flow rates to the diffusers can easily be varied with turbine operation and reservoir dissolved oxygen conditions to meet requirements without excess oxygen use. The line diffuser can be designed to extend a sufficient distance into the reservoir to aerate a volume equivalent to the average daily release from the hydropower project to handle peaking operations.

Installation and maintenance costs for the TVA line diffuser are economical. The line diffuser is a two pipe system, with a gas supply header pipe and a buoyancy chamber pipe, as shown in Figure 2. Anchors are used to sink the diffuser and hold it in position near the bottom of the reservoir. The line diffusers are constructed of readily available materials that are suitable for contact with oxygen and long-term use underwater: the diffuser piping is rugged polyethylene; all metal clamps are stainless steel; the porous hoses are made of recycled tires; and the anchors are concrete-filled plastic flower pots. The diffuser can be assembled and deployed without divers because the buoyancy pipe supports the entire weight of the diffuser in water, including the concrete anchors. Once the assembled diffuser is positioned on the water surface above the desired location, the buoyancy pipe is flooded to allow the diffuser to sink in a controlled manner to the reservoir bottom. The process is reversed to retrieve a diffuser for repositioning or maintenance. TVA diffuser installations have been in operation for more than five years thus far without demonstrating any clogging problems or need for maintenance other than design changes for the anchor attachment.

TVA Installations

TVA has over 25 years of experience in the design and installation of reservoir aeration diffuser systems including; ceramic diffusers (Ruane and Vigander, 1972; Fain, 1978), flexible membrane diffusers (Mobley, 1989), porous hose diffuser frames (Mobley and Brock, 1994) and line diffusers (Mobley and Brock, 1996). TVA has installed over 50 kilometers (30 miles) of line diffusers to meet a large range of site-specific aeration requirements at six TVA hydropower projects, one TVA nuclear plant and two non-power reservoirs. Hydropower flows ranging from 100 cubic meters per second to 1,275 cubic meters per second (3,600 cfs to 45,000 cfs) have successfully been aerated to target levels. Several of the installations aerate the entire instantaneous turbine flow while others operate continuously to meet large peaking requirements.

Costs

TVA is operating line diffuser systems using oxygen at six hydropower projects; Douglas, Cherokee, Fort Loudoun, and Watts Bar in Tennessee, Hiwassee in North Carolina, and Blue Ridge in Georgia. The installation costs for the line diffusers and oxygen supply facilities at each site varied from about $600,000 for a 12 ton per day oxygen capacity system to almost $2 million for a 150 ton per day capacity. Installation costs vary widely at each project due to site specific considerations. Costs are generally split almost evenly between the diffuser system and the oxygen supply facility for the smaller installations with the diffusers accounting for a larger percentage of the costs for the larger installations. TVA has recently installed line diffusers and underwater supply lines at a cost of $25 to $30 per foot. These cost vary with the total amount of diffusers and site specific conditions. TVA has spent a total of about $600,000 to $900,000 in annual oxygen costs to operate these six systems. The oxygen usage at each project can vary dramatically due to changing daily hydropower water flow rates that affect both the amount of water to be aerated and the reservoir oxygen demand.

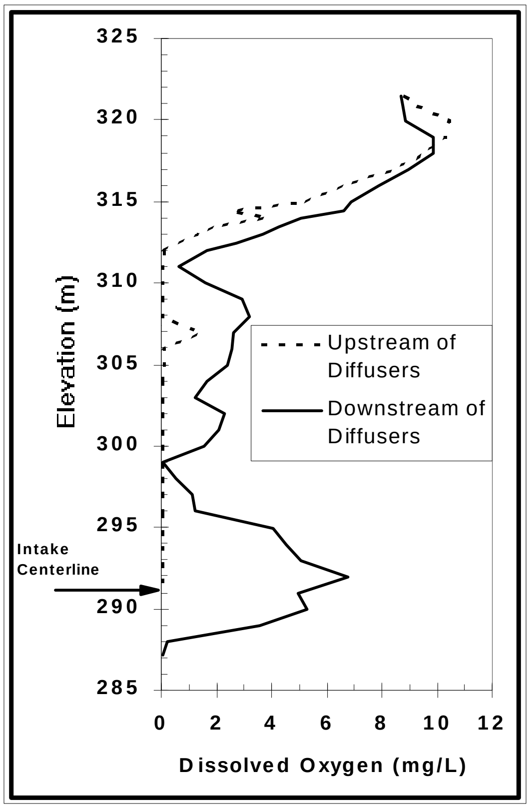
Results

In five years of operating experience, TVA has obtained satisfactory results in the operation of the line diffuser systems. The porous hoses have maintained their bubble pattern and have proven to be resistant to clogging and damage. Constant tailwater monitoring and frequent oxygen flow adjustments have been used by TVA to control oxygen usage.

Reservoir water quality profiles have displayed dramatic increases of dissolved oxygen in the hypolimnion with no significant disruption of thermal stratification. Representative reservoir dissolved oxygen and temperature profiles upstream and downstream of the oxygen diffuser installation at Cherokee Dam are shown in Figure 3. Several profiles along the length of the oxygen diffusers are shown for Blue Ridge Dam in Figure 4. A TVA line diffuser installation in Madrid, Spain was successful in reducing total dissolved iron in the reservoir to minimize water supply treatment costs.

The aerated hypolimnion around the diffusers can provide a cold water refuge for several fish species. The line diffuser installation at Cherokee attracted large numbers of striped bass and striped bass fishermen (Simmons, 1995).

Dissolved oxygen improvements in the reservoir releases are the ultimate goal of the diffuser installations at hydropower projects. TVA has maintained much improved dissolved oxygen levels as shown in Figure 5 for Douglas in 1996. The warmwater fish communities downstream from Douglas have shown improvement since aeration and minimum flow targets have been maintained (Scott et al., 1996).



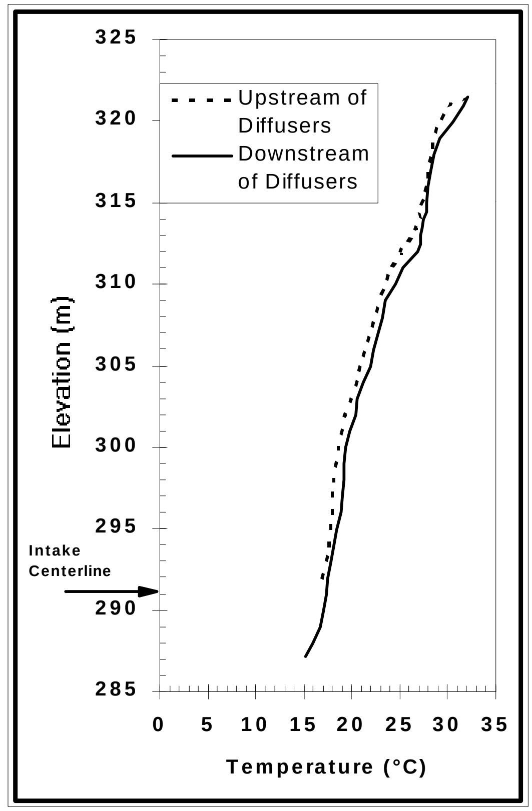
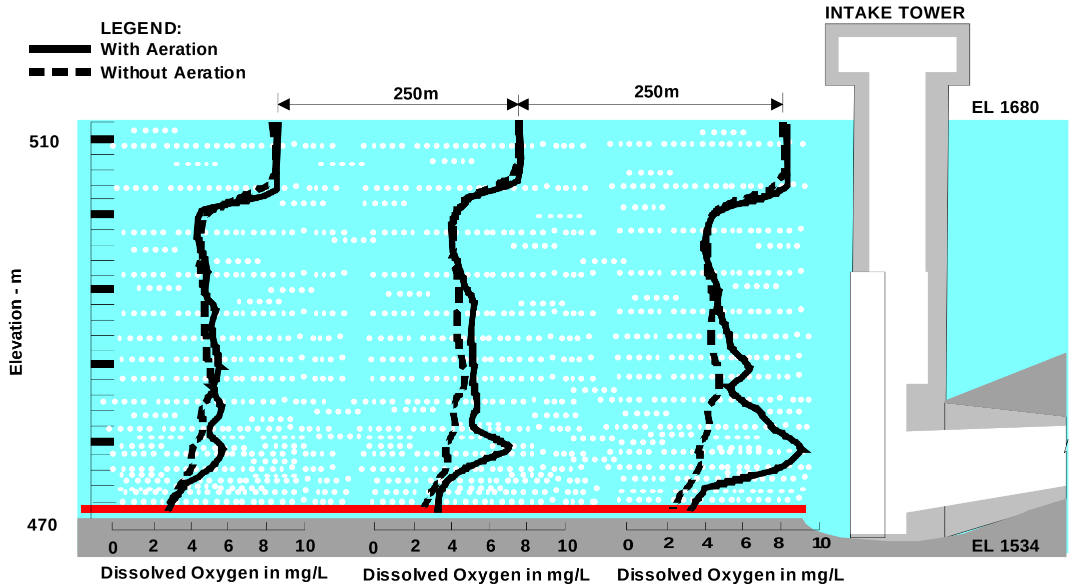


Figure 3. Reservoir Profiles At Cherokee Dam, August 14, 1995

DISSOLVED OXYGEN



TEMPERATURE

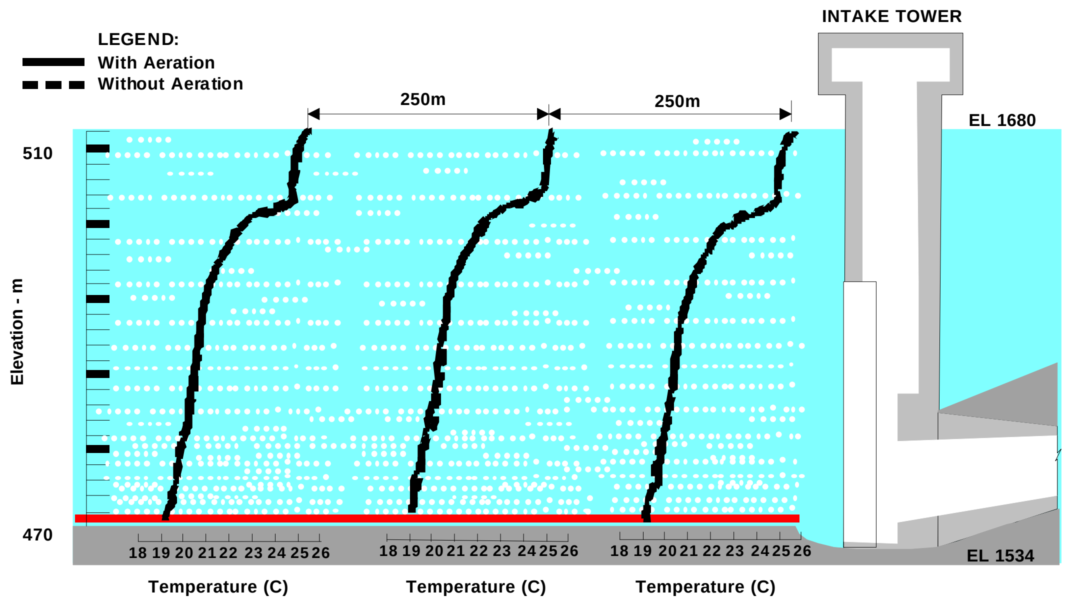


Figure 4. Reservoir Profiles At Blue Ridge Dam, September 14, 1995

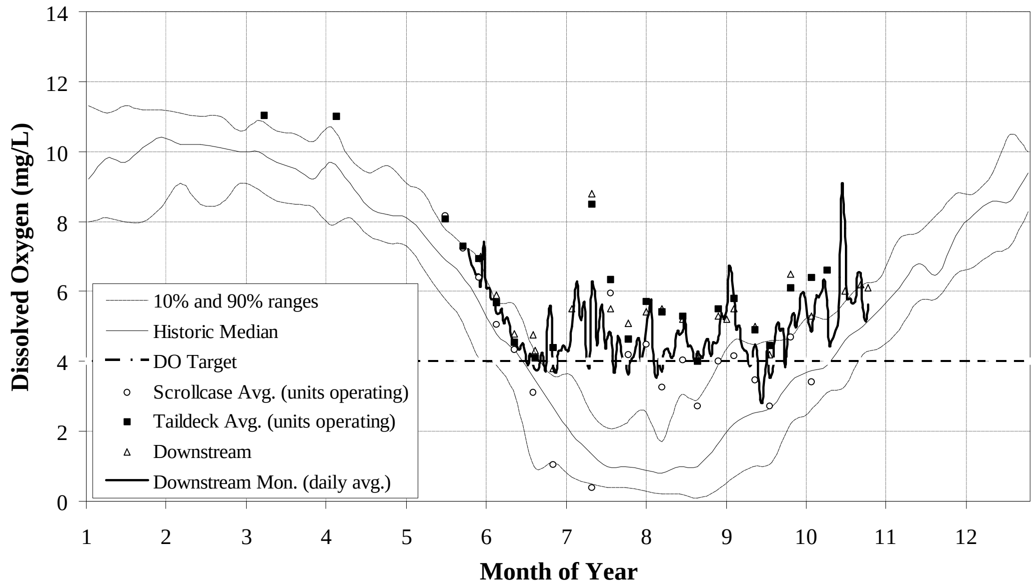


Figure 5. Reservoir Release Dissolved Oxygen Levels at Douglas Dam, 1996

Conclusion

The TVA line diffuser is an economical solution for meeting difficult dissolved oxygen requirements at hydropower projects. The line diffusers are designed to be installed and maintained without the use of divers, greatly reducing installation and maintenance costs. Operational costs are minimized due to high oxygen transfer efficiency and operational flexibility. TVA has developed a high level of expertise from the solution of a variety of aeration problems with these systems at six of its hydropower installations.

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