VENTING HYDROTURBINES FOR DISSOLVED OXYGEN ENHANCEMENT

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Abstract

Dissolved oxygen (DO) enhancement activities have been underway for the past two years on the Provo River downstream of the U.S. Bureau of Reclamation's Deer Creek Dam and Powerplant. A feasibility test during the summer of 1993 demonstrated that a combination of turbine aeration and weir aeration over the tailrace control gates could economically improve DO concentrations immediately downstream of the powerplant. Turbine aeration consisted of injecting compressed air into each turbine through the vacuum breaker system and snorkel tube. Turbine aeration can include physical modifications such as installing hub baffles on the crown of the runner, but that was not done in this case.

In the summer of 1994 both turbine and weir aeration were implemented for two months during the most severe low-DO period. Biological studies were conducted before and during the aeration effort in an attempt to determine the fishery response to DO improvements. Unfortunately, the effectiveness of turbine aeration was limited by low reservoir head caused by very dry conditions in central Utah in 1994. Weir aeration was not impacted by the low reservoir levels and was thus more effective. The response of fish populations to low DO levels varied. Fish condition did not exhibit downward trends during low-DO periods. However, fish exposed to low DO were lethargic and unable to recover from handling stress. Invertebrate populations were dominated by species tolerant of poor water quality.

This paper describes the activities and results of the efforts at Deer Creek Powerplant and also discusses some additional alternatives for improving DO concentrations downstream of powerplants, including reservoir aeration, reservoir mixing, molecular oxygen injection, specially designed aeration weirs or aeration infusers, and newly designed auto-venting turbines.

Background

A primary requirement for sustaining healthy fisheries and aquatic ecosystems is the presence of sufficient dissolved oxygen. In temperature-stratified reservoirs, DO is consumed deep in the reservoir by biological and chemical processes and is not replenished due to the lack of mixing inherent in stratification. The water quality problems created when this low-DO water is released through powerplants have become a special concern for many hydro operators. DO enhancement may be achieved by many methods, including reservoir mixing, reservoir aeration, and turbine aeration. In recent years the Tennessee Valley Authority (TVA) has led efforts to improve turbine designs to incorporate turbine aeration. In the seventeen western states with projects administered by Reclamation, the low-DO problem has been less severe than in the southeastern U.S., primarily due to the reduced productivity of most western reservoirs and the presence of steep rivers with good natural reaeration properties. For many years Reclamation has dealt with problems of nitrogen supersaturation and resulting gas-bubble disease in fish downstream of energy dissipation structures, and outlet works. Dissolved oxygen problems have thus far been more limited, although still serious in some cases.

Project Description

Deer Creek Reservoir is a key storage element of the Bureau of Reclamation's Provo River Project. The reservoir is located about 24 km (15 miles) upstream of Provo, Utah and receives inflow from a watershed with extensive agricultural use and increasing urban development. During late summer, releases from the reservoir are made entirely through the powerplant and often have DO concentrations ranging from 0 to 2 mg/L. The low-DO problem impacts about 3 to 5 km (2 to 3 miles) of heavily used blue ribbon trout fishery on the Provo River below the dam. Efforts are underway to reduce the low-DO problem with improved watershed management and operation of the selective withdrawal structure at recently completed Jordanelle Dam, about 16 km (10 miles) upstream on the Provo River.

The powerplant, constructed in 1958, contains two Francis-type turbines rated at 2475 kW each. Rated head and discharge for each turbine are 36.6 m (120 ft) and 8.5 m^3/s (300 ft^3/s), respectively. Maximum head is 42.7 m (140 ft). The draft tubes on both units are simple conical diffusers discharging into prismatic chambers leading to the tailrace (fig. 1). Water levels in the tailrace below the powerplant are controlled by an overflow gate structure consisting of three 4.57-m (15-ft) wide flap gates. The powerplant is operated by the Provo River Water Users Association (PRWUA).

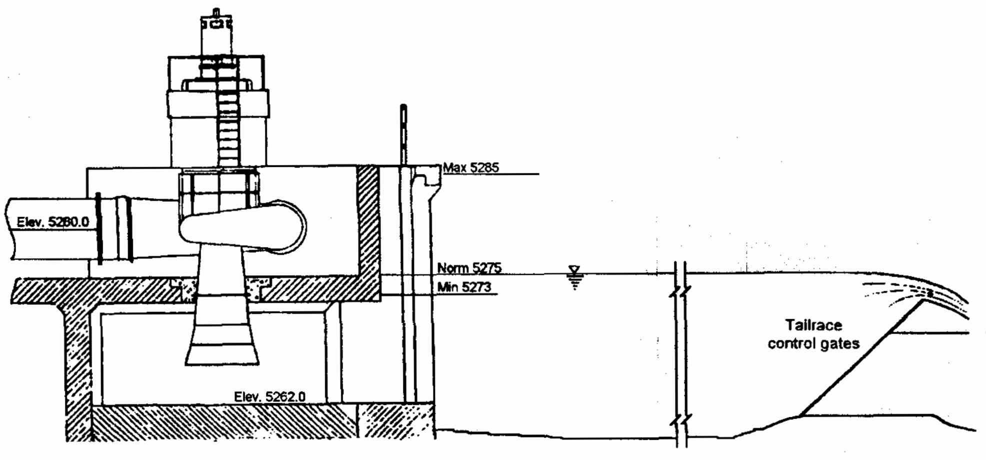

Figure 1. - Cross section through Deer Creek Powerplant showing turbine draft tube and tailrace configuration. The tailrace is approximately 5 m deep, 15-20 m wide, and 80 m long.

During the winter of 1992-93, drought conditions caused Reclamation to restrict reservoir releases to about 85 percent of the required instream flow. To mitigate for this low-flow event, Reclamation proposed several alternatives for raising dissolved oxygen concentrations in the river downstream of the powerplant, with the objective of achieving DO levels in the 4 to 5 mg/L range (Young et al., 1994). A project team was formed with representatives from Reclamation, the U.S. Fish and Wildlife Service, the PRWUA, the Central Utah Water Conservancy District, the Utah Division of Wildlife Resources, and the National Biological Service.

Feasibility Test - 1993

Reclamation tested the feasibility of active turbine aeration (injection of compressed air) during a 3-day test in the summer of 1993 (Wahl et al., 1994). Objectives were to determine the effectiveness of aeration for increasing DO concentrations and to collect data needed to implement turbine aeration on a more permanent basis. We especially hoped to determine whether passive aeration (venting to the atmosphere) without air compressors could be effective. Much of our uncertainty regarding the possible effectiveness of turbine aeration was due to the configuration of the draft tubes (fig. 1), which is quite different from most cases documented in the literature. The lack of a formed elbow section causes low flow velocities in the chamber leading to the tailrace, and we suspected that air bubbles would quickly coalescence near the top of this chamber, limiting the possible gas transfer. To achieve good DO uptake, the majority of gas transfer would have to occur quickly, in the conical diffuser portion of the draft tube. Another factor that might limit the DO transfer was the relatively high setting of the units. Because the saturation concentration of DO increases with pressure and the gas transfer is directly related to the deficit from saturation, the best DO increase occurs when air bubbles can be carried well below the tailrace water surface. The deepest portion of these draft tubes is only about 3 m (9 ft) below the normal tailrace water level.

The reservoir was near maximum capacity at the time of the test. Air was injected through the vacuum breaker systems and through the snorkel tubes of each turbine unit (fig. 2) using two air compressors, each with a rated capacity of 21.2 m^3/min (750 scfm). We expected to get the greatest airflow through the vacuum breaker system due to its larger pipe diameter (5 cm on the vacuum breaker, versus 2.5 cm on the snorkel tube). DO concentrations were measured upstream of the turbines (on a line carrying cooling water from the penstock to the turbine bearings) and in the tailrace pool. We also tested the concept of raising the tailrace control gates to create a free overfall for additional aeration.

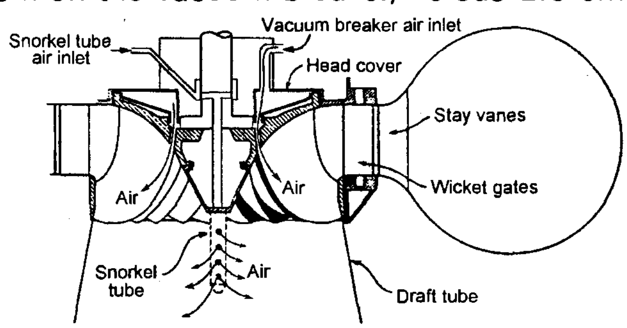

Figure 2. - Air was injected into the turbines through the vacuum breaker system and through the snorkel tube.

The tests showed that turbine air injection and weir aeration were both effective. Pressures within the turbines were well below atmospheric for all tested operating conditions; thus, significant DO improvement could be achieved with passive aeration. We estimated that, depending on turbine discharge, passive turbine aeration could produce DO increases ranging from 0.4 to 1.6 mg/L during a typical summer. We also collected information needed to estimate power losses caused by turbine aeration, and monitored bearing temperatures and runouts to ensure that aeration did not adversely affect the mechanical operation of the turbines.

Figure 3 shows the results of the turbine aeration portion of the tests. The DO increase is expressed in terms of aeration efficiency, that is the percentage increase in DO compared to the initial deficit from saturation. The airflow is expressed as a volumetric percentage of the water discharge through the turbines (air volume computed at standard temperature and pressure). For airflow rates up to about 4 percent, the aeration efficiency increased about 10 percent for each additional 1 percent air. At the time of the tests the incoming DO concentration was about 2 mg/L, and the saturation concentration at the water surface was about 9 mg/L, so a 40 percent aeration efficiency would correspond to a DO increase of about 2.8 mg/L, for a final concentration downstream of the turbines of 4.8 mg/L.

Power losses due to turbine aeration were consistent with the reports of other investigators (Almquist et al., 1991). In the range of typical operating conditions, each 1 percent additional airflow caused a turbine efficiency loss of about 0.5 percent. At very low gate operation, where draft tube surging would typically be present, aeration produced a slight increase in turbine efficiency.

Weir aeration across the tailrace gates was achieved by raising the gates 0.91 m (3 ft) to produce a free overfall across the gate. The aeration efficiency across the gate was about 20 percent. The price for this DO increase is a 2 to 3 percent efficiency loss due to the reduction in net head across the turbines. This compares to a 1 percent efficiency loss using turbine aeration at a 2 percent airflow rate, which also produced about 20 percent aeration efficiency.

The testing with the tailrace gates raised also allowed us to evaluate the influence of tailwater level on the effectiveness of turbine aeration. We hoped that higher tailrace water levels would increase DO uptake by increasing the pressure within the draft tube and increasing bubble contact time in the tailrace. However, we did not observe a significant change in aeration efficiency when tailwater levels were raised. This result may have been due to the limited range of possible tailwater adjustments. One factor limiting the effectiveness of turbine aeration was the draft tube

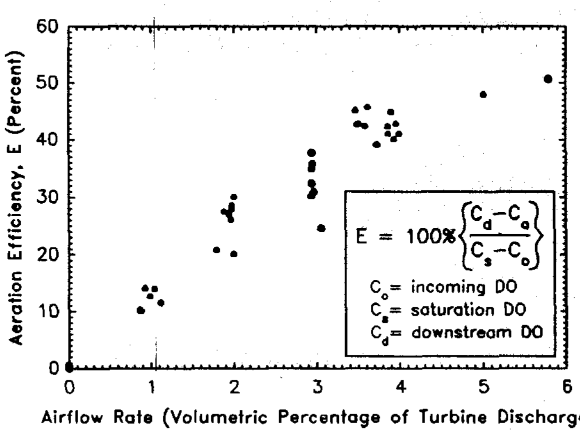

***Figure 3.** - Turbine aeration efficiency as a function of airflow rate.*

configuration. Large quantities of air coalesced at the top of the prismatic chamber described previously, and were vented out in large surges at the downstream face of the powerhouse. This reduced the amount of air available for possible gas transfer in the tailwater pool. Despite this air loss, we did observe bubbles well out into the tailrace during all of the turbine aeration tests.

We did not find any significant difference in aeration efficiency as a function of the air injection location, although the required injection pressure for a given flowrate was much lower on the vacuum breaker system, as expected. We found that the vacuum breaker plumbing on unit number 1 was partially plugged, severely limiting the airflow into that unit.

Implementation - 1994

Based on the results of the 1993 tests, the turbine and weir aeration options were pursued for implementation during the summer of 1994. To make turbine aeration most effective, axial blowers were considered for installation at the powerplant. Two blowers, each with a capacity of 21.2 m^3/min (750 scfm) at a discharge pressure of 103 kPa (15 psi), would provide the ability to inject up to 5 percent air at maximum turbine discharge. However, a $100,000 upgrade to the plant electrical service was required to provide power to the blower motors. This far exceeded available funding, so we chose to pursue a low-cost alternative, combined weir aeration and passive turbine aeration. For this option the only monetary cost was the lost power revenue caused by efficiency losses. The disadvantage of passive aeration was that the relative airflow percentage and DO uptake would be low when the powerplant discharge was the highest.

The inlets to the vacuum breaker system and snorkel tube on each unit were fitted with protective air relief valves to prevent any backflow of water into the turbine pits in case of high tailwater levels. We were unable to remove the blockage from the vacuum breaker line on turbine unit 1. The blockage appeared to be a remnant of previous welding activity and could not be removed without complete disassembly of the unit.

Weir aeration was implemented as tested in 1993, except that the tailrace gate heights were limited to 0.61 m (2 ft) to minimize seepage into the drainage gallery of the powerplant. Reclamation agreed to reimburse the PRWUA for the value of the power losses caused by both aeration activities.

Data collection to evaluate the hydraulic and water quality aspects of the aeration effort consisted of:

- DO measurements upstream and downstream of the powerplant and downstream of the tailrace gates,
- Wicket gate position, discharge, head, and power output measurements in the powerplant

- Static vacuum pressure measurements at each air inlet to permit estimation of airflow rates into the turbines
- Total dissolved gas testing to ensure that aeration was not creating a nitrogen supersaturation problem in the tailrace

To assess the biological effects of aeration, baseline conditions were established prior to the aeration season through a trout movement study, a creel census, and invertebrate community studies. DO levels were allowed to drop naturally to 2 mg/L or lower for a two-week period early in the summer to determine biological response to low-DO conditions. Once turbine aeration was begun, the same studies were continued throughout the summer to evaluate the biological response to the elevated DO levels.

Operating Conditions. — Turbine aeration was started in mid-August on both turbines. Aeration was ended on September 30 on unit 2, and on October 10 on unit 1. The tailrace gates were raised either 0.3, 0.46, or 0.61 m (1.0, 1.5, or 2.0 ft) from August 16 to October 1. Total head across the turbines ranged from about 35.4 m (116 ft) on August 16 to about 30.5 m (100 ft) in late September. This was well below the maximum-head conditions (42.7 m; 140 ft) experienced in 1993.

Due to the lower reservoir head, turbine wicket gate openings during the 1994 implementation period were about 7 to 10 percent higher for a given flow than those used during the 1993 tests. Power outputs for a given flow rate were about 20 to 25 percent lower. Due to severe drought conditions, flowrates were kept higher than normal throughout the summer of 1994 to provide water to downstream users.

Airflow Into Turbines. — Actual airflow rates were not measured during the 1994 aeration period, but vacuum pressure measurements and the results of the 1993 test were used to estimate airflow rates. The vacuum pressures recorded were much lower (less vacuum) than in 1993, due to the reduced reservoir head. Estimated airflows throughout the aeration period were only about 0.7 to 1.4 m^3/min (25 to 50 scfm) into each turbine, with an average of about 0.99 m^3/min (35 scfm) per turbine. On a volumetric percentage basis, airflow rates ranged from 0.15 to 0.6 percent. The highest percentage airflows occurred in late September and October when the turbine discharges were the lowest. For comparison, airflow rates as high as 6 percent were achieved during the 1993 test, using compressors to actively blow air into the turbines. If reservoir levels similar to those in 1993 had prevailed during the summer of 1994, airflow rates as high as 1.4 percent by volume could have been achieved through the passive aeration technique.

DO Increases Due To Turbine Aeration. — The low airflow rates led to disappointing increases in DO concentration through the turbines. Based on the estimated airflow rates and results of the feasibility test, DO increases of 0.2 mg/L or less were predicted. This DO change was so small that it could not be reliably detected.

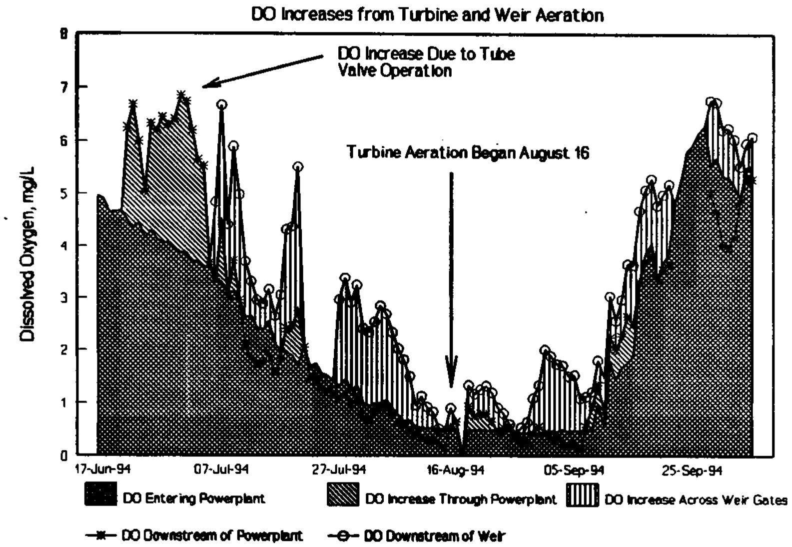

Figure 4. - DO concentration changes through Deer Creek Powerplant and over the tailrace weir gates (mean daily values). Operation of the tube valve outlet works produces extreme aeration of the tailrace basin. The reservoir turned over during the last two weeks of September.

Figure 4 shows the DO concentrations upstream of the powerplant, downstream of the powerplant (just above the tailrace weir gates), and downstream of the tailrace weir gates. It should be noted that there are several periods of missing data for the sensors located downstream of the powerplant and downstream of the weir gates. There also are some periods in which the data are inconsistent; DO concentrations downstream of the powerplant are reported to be less than the DO at the dam (entering the powerplant). This is believed to be due to a faulty DO reading downstream of the powerplant.

Weir Aeration. — The weir gates were raised for much of the summer, even prior to the start of turbine aeration, to maintain tailrace levels required for a diversion structure drawing water from the tailrace. Increases in DO concentration as high as 2 mg/L were achieved across the raised tailrace gates, with the largest DO increases occurring as the total powerplant discharge (and the unit discharge across the gates) decreased. Figure 5 shows the increase in aeration efficiency with decreasing discharge. The height of the weir gates did not appear to have a significant effect on the aeration efficiency, although the gates were held at a constant height of 0.61 m (2 ft) for most of the summer.

Nitrogen Supersaturation Tests. — Total dissolved gas measurements were made in the spring of 1994 and during the aeration period from mid-August through September. Readings were taken upstream of the turbines, in the tailrace, and in the river downstream of the tailrace gates. Dissolved nitrogen concentrations were in the range of 100 to 110% of saturation upstream of the turbines both before and during the aeration period, indicating a pre-existing supersaturation condition in the reservoir. Dissolved nitrogen concentrations were reduced downstream of the turbines and weir gates during the aeration period, although there was still slight supersaturation throughout the study. Turbine and weir aeration both showed promise for improving nitrogen supersaturation conditions.

Biological Response to DO Enhancement. — Fish populations were sampled at four stations in April, August, and October. Brown trout dominated the samples. Water temperatures ranged from 10 to 18°C during the study period; optimal DO levels for these temperatures are 9 to 12 mg/L. Trout marked at upper stations, where DO was poor, were observed to generally move downstream. Trout marked at downstream locations exhibited limited movement. Trout population estimates, however, indicated increased trout numbers at the uppermost station during the study. These data, when considered with the marked fish data, indicate that movement occurred throughout the study period, with trout populations being replaced between sampling efforts. Trout condition factors at all four stations generally increased through the study period. Condition factors were comparable to brown trout in seven North American streams as reported by Carlander (1969), but fish collected at upper stations during low-DO periods exhibited extreme lethargy, and were not able to recover from handling stress. Fish at lower stations did not exhibit these characteristics. Creel census data also indicated similar trends; anglers reported minimal angling success in the upper stations, whereas catch rates remained high in the lower stations.

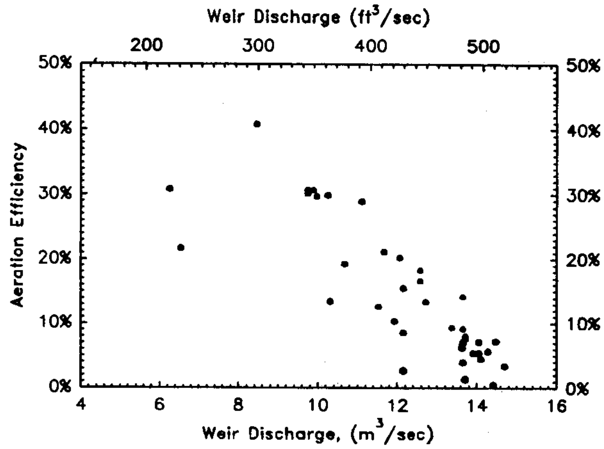

Figure 5. - *Weir aeration efficiency versus discharge.*

Aquatic invertebrate samples at an upstream and downstream station were dominated by species tolerant of sediment, organic enrichment, and adverse water chemistry. Less tolerant species were reduced in numbers or absent, indicating a long-term, detrimental impact from annual low-DO conditions. Biomass estimates (combined plant and animal life) were extremely high for all sample periods, whereas biotic condition and diversity were low. Limited colonization of these stations by less tolerant invertebrates was noted during improved DO conditions.

Turbine Aeration Recommendations. — The primary reason for the low airflows and corresponding low DO improvements was the reduced reservoir level during 1994. The reduced head significantly alters flow conditions within the turbines, leading to higher absolute pressures on the vacuum breaker air ports in the crown of the runner (the primary source of airflow on these units). To improve turbine aeration under these conditions, hub baffles could be added to the units (fig. 6). Baffles deflect flow away from the runner crown at the vacuum breaker air ports to create a low pressure zone that helps draw additional air into the turbine. Hub baffles were first described by Raney and Arnold (1973). Baffles were not added initially at Deer Creek because the results of the 1993 feasibility test (without baffles) were very encouraging at high reservoir levels. Also, this was Reclamation's and PRWUA's first experience with turbine aeration, and as a result we wanted to minimize permanent alterations to the turbines.

The Deer Creek results are similar to observations at the Tennessee Valley Authority's Cherokee Powerplant. The turbines at Cherokee are similar in size and head range to those at Deer Creek. TVA observed that the Cherokee units drew large quantities of air at maximum head conditions, but little or no air as the reservoir dropped toward its minimum level. TVA has now installed hub baffles that maintain high airflow rates over the full range of operating heads. The baffles do cause a slight efficiency loss due to the disruption they cause to the flow through the turbine. This loss is incurred year-round and is in addition to the losses caused by aeration. Jones and March (1991) report a 0.4 percent efficiency loss due to the baffles at TVA's Norris Powerplant. TVA has an extensive program to install aeration baffles at many of their powerplants.

The baffle installation process is generally straightforward. Baffles are welded onto the crown immediately upstream of the air ports (7 ports on each of the Deer Creek units). Baffle installation generally does not create any additional maintenance problems. TVA has found that the baffles can cause some increase in cavitation, but that cavitation damage is confined to the baffles themselves or to the crown in the immediate vicinity of each baffle. Cavitation damage observed by TVA has been light in all cases.

Future Plans

Feasibility tests conducted at high reservoir heads in 1993 showed that passive turbine aeration could effectively enhance DO concentrations of releases from Deer Creek Powerplant. A two-month implementation during the summer of 1994 was less successful due to low reservoir head and high powerplant discharges. Turbine aeration performance could be improved through the installation of hub baffles and/or the installation of blowers to allow forced air injection into the turbines. Either alternative would produce more consistent turbine aeration results by providing relatively high airflows into the turbines under a variety of operating conditions.

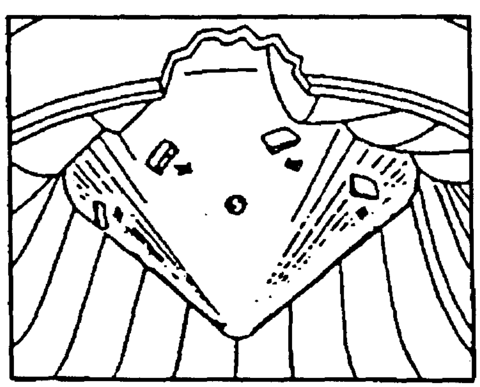

Figure 6. *- Typical hub baffle installation. Baffles deflect flow away from the vacuum breaker ports in the runner crown.*

Aeration of flow over the tailrace gates was effective in both 1993 and 1994. Power losses caused by raising the gates were much greater than the losses caused by turbine aeration; the low airflow rates into the turbines minimized the power losses due to aeration. Total power losses for the two-month aeration period were estimated to be 63 MWh. Five percent of this loss was attributed to turbine aeration, and 95 percent was attributed to the raising of the tailrace gates. Much of the power loss associated with the weir aeration might also be incurred without weir aeration, since the gates must be raised for part of the summer to provide for water deliveries.

In a more typical year and for similar levels of DO enhancement, weir aeration would cause about twice as much power loss as passive turbine aeration. Forced air injection would cause power losses due to reduced turbine efficiency, and there would be costs associated with blower operation. For this site, power required to run the blowers to provide a 2 percent airflow rate was estimated to be about 1 percent of the total generating capacity of the powerplant. Thus, total operational costs and power losses for forced air injection would be comparable to losses due to weir aeration, for similar DO benefits. In addition, there are significant capital costs to install blowers, motors, and other equipment needed for forced air injection.

Although the overall results in 1994 were disappointing, Reclamation and the other members of the project team hope to continue aeration activities at this site in the future. When the opportunity arises in the course of normal maintenance, the blockage in the vacuum breaker system of turbine unit 1 will be removed. Based on the results of the biological monitoring, the Utah Division of Wildlife Resources is encouraging the use of weir aeration and further study of nitrogen supersaturation conditions.

Other Aeration Alternatives

Turbine aeration is an effective and economical aeration alternative for many situations. Its greatest advantage is that it treats the water at the point of release, thereby minimizing the quantity of flow to be treated. Turbine aeration also is quite effective because aeration is performed at a point where the flow is receptive to aeration due to high turbulence. Despite these advantages, there are other alternatives that may prove valuable for some situations (Bohac and Ruane, 1990). As we increasingly focus our attention on the habitat value and water quality of our powerplant tailwater areas, Reclamation may face future problems similar to those at Deer Creek Powerplant. Thus, discussion of some of these other DO enhancement methods may prove useful.

Aeration alternatives can be categorized by location as follows: forebay aeration or mixing; penstock aeration; turbine or draft tube aeration; and tailrace aeration using existing or specially designed weirs or aeration structures.

Forebay aeration alternatives. — Forebay aeration alternatives include both mixing and aeration options. Forebay aeration methods can be costly as they must treat additional water in the reservoir besides the water being released through the powerplant. Advantages of forebay methods are the minimal impact on powerplant output and operations.

Surface mixers can be used to push high-DO surface waters down to the level of the powerplant intakes. Disadvantages of this technique in some cases are altered release temperatures and possible impacts on reservoir water quality due to the breakup of natural stratification patterns.

Aeration of the low-DO waters in the hypolimnion can be achieved using diffusers installed in the reservoir upstream of the powerplant intakes. Either compressed air or molecular oxygen can be used. The use of molecular oxygen helps to avoid the creation of nitrogen supersaturation problems as a result of the aeration efforts, but creates additional expense and logistical problems related to the handling and dispensing of liquid oxygen. Aeration in the hypolimnion can also be used create mixing of the hypolimnion and epilimnion to achieve effects similar to the surface mixing options. For cases in which the breakup of natural stratification problems is undesirable, special hypolimnetic aerators can be used to aerate just the hypolimnion without causing destratification.

Penstock aeration. — Aeration within long penstocks can be more effective than turbine aeration. Penstock aeration treats only the water being released, and contact times can be much longer than for turbine aeration. Compressed air must be supplied at much higher pressures than for turbine aeration, but the increased pressure in the penstock also produces very high oxygen transfer efficiencies because the saturation concentration increases with pressure, thus increasing the DO deficit, one of the driving parameters in the gas transfer process. Molecular oxygen should again be considered to avoid nitrogen supersaturation problems. TVA has tested penstock aeration at Douglas Dam, using garden-type soaker hoses to inject oxygen along the invert of the penstock several hundred meters upstream of the turbines. At Douglas, 80-90 percent of the injected oxygen is transferred into DO in the release water. Difficult access can be a major obstacle to overcome for penstock aeration.

Additional turbine aeration alternatives. — Figure 7 shows several additional turbine aeration alternatives. TVA and Voith Hydro performed model tests of each of these alternatives in preparation for the runner replacement on unit 2 at TVA's Norris Dam. The new runner is presently being installed and will allow for aeration through the hub deflector, the thrust relief/vacuum breaker system (also tested at Deer Creek), the discharge edge of each runner blade, and through a deflector ring around the draft tube cone. Each of these locations showed promise in the model tests and will be further evaluated once the upgraded unit is operational.

Tailrace aeration. — Tailrace aeration devices treat only the release water and minimize impacts on powerplant output, as long as they are located far enough donwstream to avoid producing additional backwater on the powerplant. There are a variety of aeration weirs and other devices that can be used, including some that also provide reregulation of powerplant releases. Existing weirs or gates that produce a free overfall can be used to achieve aeration just as the tailrace gates were used at Deer Creek Powerplant. Two notable devices that fulfill reregulation and aeration needs are the labyrinth aeration weir and the aerating infuser, both developed by TVA.

Figure 8 shows a labyrinth aeration weir. The weir uses a labyrinth design to increase the crest length and thus reduce unit discharges over the weir to levels at which the flow will be effectively aerated. Hauser et al. (1991) report testing of a labyrinth aeration weir designed to increase DO from 2 mg/L to as much as 5-6 mg/L; the unit discharge over the weir was 0.111 $m^3/s/m$ (1.2 $ft^3/s/ft$) with a drop height of 1.37 m (4.5 ft). Keeping the unit discharge low improves both aeration performance and safety of the structure, when swimmers are expected in the vicinity of the weir. This weir was constructed of reinforced concrete piers and tongue-and-groove timber members. Pipes and valves included in the design are used to maintain minimum flows through the structure.

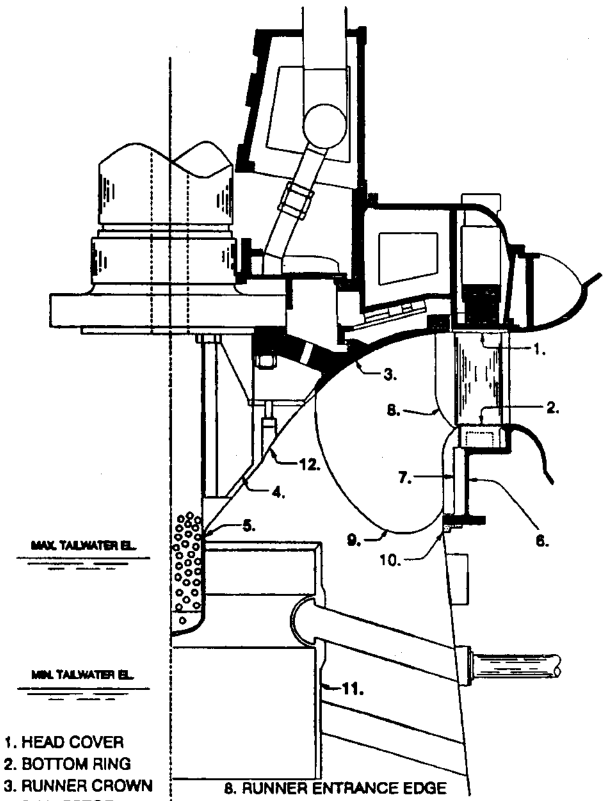

Figure 7. *- Alternative aeration locations on a typical hydroturbine (Waldrop, 1991).*

Figure 9 shows TVA's aerating infuser, tested on the Hiwassee River below Chatuge Dam (Hauser and Brock, 1994). The aerating infuser is designed to occupy less space in the channel than the labyrinth weir while maintaining similar crest length and aeration performance. The infuser is typically more cost-effective than the labyrinth for high-flow applications.

The infuser is essentially a hollow broad-crested weir, with a porous grating installed on the downstream portion of the crest to allow curtains of water to drop through the grating into the tailwater downstream of the weir. A timber crib filled with loose rock forms the upstream portion of the infuser, and is lined with tongue-and-groove timbers to make it impermeable. Pipes through the timber crib and associated float valves maintain minimum discharges when the upstream powerplant is not operating. When the powerplant is operating, flow travels over the timber crib and then drops through the infuser deck attached to the downstream side of the timber crib. The deck is made from a standard steel foot grating. Chimneys through the infuser deck allow free circulation of air beneath the infuser to aerate the flow dropping through the grating. Initial tests have shown the infusers to be very effective; the Chatuge

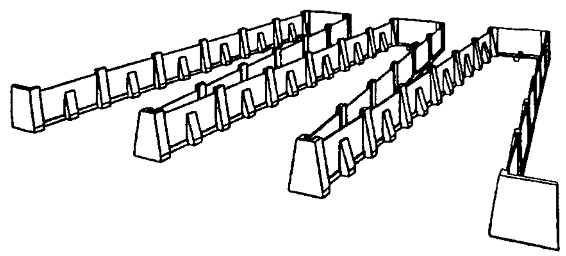

Figure 8. *- Labyrinth aeration and reregulation weir (Hauser et al., 1991)*

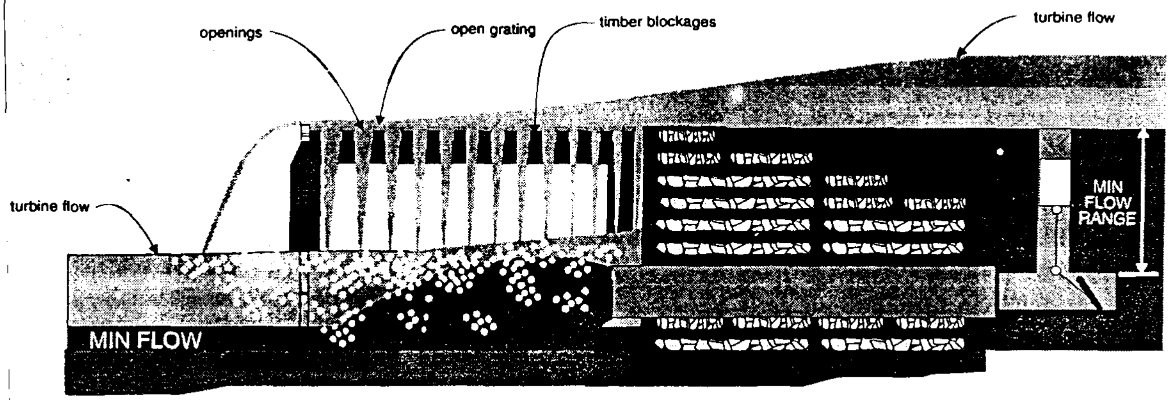

Figure 9. - Aerating infuser (Hauser and Brock, 1994).

infuser recovers about 65-70 percent of the DO deficit when the turbines are operating, with a drop height of 2.1 m (6.9 ft).

Acknowledgments

The studies at Deer Creek Powerplant were a cooperative effort of the Central Utah Water Conservancy District, Provo River Water Users Association, Utah Division of Wildlife Resources, U.S. Fish and Wildlife Service, and Reclamation's offices in Salt Lake City, Provo, and Denver. Key Reclamation participants in the 1993 and 1994 tests included: Doug Young (formerly of the UC Regional Office and now with the U.S. Fish & Wildlife Service in Salt Lake City); Jonathan Jones (Provo); Jerry Miller and Walt Payne (Salt Lake City); and Lee Elgin and Bill Duncan (Denver). The powerplant operators, Harold Ford, Jack Powers, Frank Severson and Earl Laycock (Provo River Water Users Association) also provided valuable assistance. Reed Oberndorfer (Central Utah Water Conservancy District) assisted with the DO instrumentation and measurements. Charlie Thompson (Utah Division of Wildlife Resources) assisted with biological monitoring for the 1994 tests. Mark Mobley and Paul Hopping at TVA provided much of the background material on TVA's aeration activities.

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