Aerating Weirs For Management of Reservoir Releases

Gary E. Hauser

TVA Engineering Services, P. O. Drawer E, Norris, TN 37828

W. Gary Brock

TVA Water Management, 400 West Summit Hill Drive, Knoxville, TN 37902

Introduction

Two of the most significant environmental impacts of hydropower dams on downstream tailwater reaches in the Tennessee River Valley are 1) low dissolved oxygen (DO) concentrations during hydroelectric generation; and 2) lack of suitable minimum flow between generating periods. High-performance weirs are one of several technologies now considered at hydropower dams as part of TVA's Lake Improvement Plan, which is implementing various DO and minimum flow technologies at 16 dams by 1996. TVA has been developing, testing, designing, and constructing innovative aerating weirs to meet release improvement objectives since 1990. Aerating weirs are attractive compared to in-reservoir and in-hydroplant aeration methods because they are passive, reliable, require little maintenance, avoid turbine damage, and are capable of meeting both DO and minimum flow objectives with a single technology. This presentation updates water resource professionals on developmental features, advantages-disadvantages, and the performance results of these weirs.

Two aerating weirs have been constructed below TVA hydropower dams. A labyrinth weir below South Holston Dam (Figure 1) on the South Fork Holston River was completed in December 1991. An infuser weir below Chatuge Dam (Figure 2) on the Hiwassee River was completed in November 1992. Although these weirs are quite different in design, aeration and minimum flow principles are similar. Reaeration of oxygen-deficient turbine releases is achieved by water overtopping the weirs and plunging into a downstream pool during generation in a process similar to natural waterfalls. Minimum flow is sustained downstream of the weirs during periods of no generation by slow drainage of the weir pools through low-level pipes fitted with float-actuated valves. These valves open gradually as the weir pools drop, maintaining a constant flow from the weirs until the next generating period or refill pulse from the upstream dam. Important geometric and hydraulic characteristics of the labyrinth and infuser are given in Table 1.

Table 1. Physical Characteristics of TVA Aerating Weirs

	South Holston Labyrinth	Chatuge Infuser
distance downstream of dam (km)	1.9	1.2
channel width at weir site (m)	104	35
height (m)	2.3	2.9
overflow crest length (m)	640	30.8
drop height (m) headwater to tailwater	1.4	2.1
turbine discharge (m^3/s)	68	37
specific discharge (m^2/s)	0.11	1.2
head on crest at turbine discharge(m)	0.15	0.76
plunge pool depth - turbine flow (m)	1.1	1.8
minimum flow target (m^3/s)	2.5	1.7
drain time between pool refills (hr)	19	13

South Holston Labyrinth Weir

The South Holston labyrinth weir has an extended crest with a repetitive "W" shape in plan view, as illustrated for three bays in Figure 1. The weir actually includes ten labyrinth bays, each with 64 m of overflow crest length. Weir walls are constructed with tongue-and-groove timbers fitted together and supported as independent wall sections in a stoplog arrangement using slotted concrete piers at 6 m intervals as wall support with concrete midspan supports for the deeper timber members.

The extended crest length of the labyrinth weir (640 m) reduces the specific discharge (flow per unit length) to a level that both aerates efficiently and avoids a dangerous recirculating hydraulic condition downstream of the waterfall (Hauser, 1991).

Aeration is achieved during overtopping as the thin nappes entrain air in a high air/water ratio in the wake of their impingement on the downstream plunge pool. The entrained air pockets burst into small bubbles that are driven deep into the plunge pool and retained in turbulence beneath the surface for several seconds before coalescing and rising to the surface. This aeration mechanism is well documented in the weir aeration literature by Nakasone (1987), Avery and Novak (1978), Kobus and Markofsky (1978), and others for conventional overfall weirs constructed normal to river flow (linear weirs). With a labyrinth weir, further aeration (about 20-30% greater deficit removal than with a simple linear overfall weir) is achieved along the length of the labyrinth legs. This additional aeration is due to re-entrainment of bubbles in downstream portions of the waterfall as the bubbles are transported to the downstream end of each labyrinth tailwater bay.

The reduced specific discharge (0.11 m^2/s) at the South Holston weir decreases the intensity of the downstream recirculation (common to any free overfall weir) to a level that is safe for wade fishermen, boaters, and other river users. According to Hauser (1991), the specific discharge at which the recirculation becomes dangerous is in the range 0.15-2.0 m^2/s if the tailwater is deep enough to force a person to swim rather than walk in the flow. The reduced specific discharge also reduces the head on the weir required to pass the turbine flow. Labyrinth weirs can therefore provide better aeration with safer overflow hydraulics, less backwater on upstream turbines, and less property inundation during flood flows, compared to conventional linear weirs.

The South Holston labyrinth weir has been meeting or exceeding aeration and minimum flow objectives with minimal operation and maintenance. The target minimum flow of 2.5 m^3/s is sustained for 19 hours between generating periods. Aeration tests at this weir have shown that 55-60% of the oxygen deficit is recovered at turbine discharge flows (1.4 m drop height). In preliminary testing in early 1992, the labyrinth weir aerated 60% of a 2 mg/L DO deficit in the South Holston Dam releases. In recent tests during the low DO season in fall 1993, DO at the weir increased from an incoming value of 2.6 mg/L to 6.9 mg/L downstream of the weir (saturation 10.4 mg/L), which represents aeration of (6.9-2.6)/(10.4-2.6) = 55% of the deficit.

Figure 3 shows results of a recent aeration test using continuous DO monitors located in mid-channel upstream and downstream of the labyrinth weir.

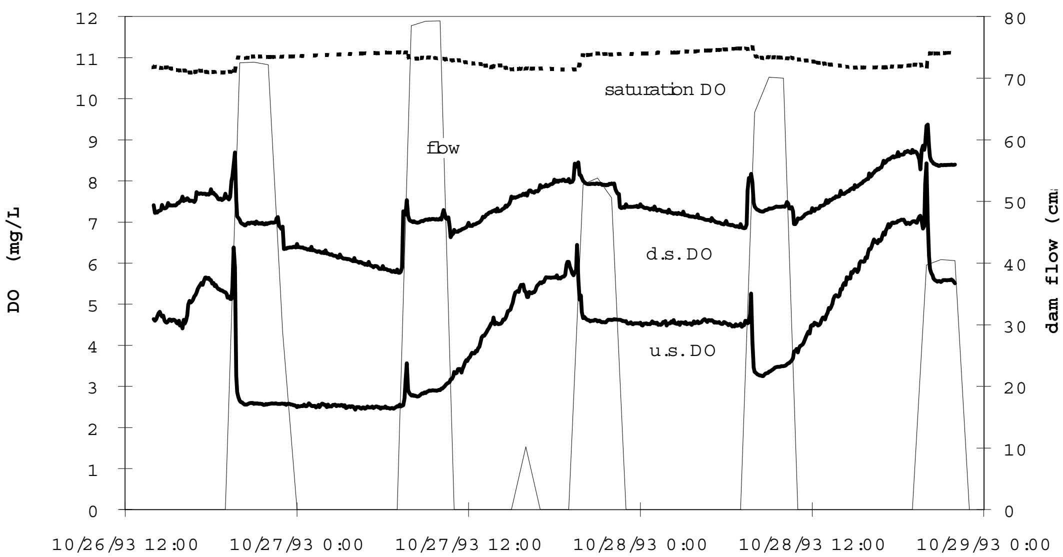

Figure 3. DO measurements above and below the South Holston labyrinth

These results show that the aeration efficiency reduces from 55% during turbine generation to about 40% of the deficit during the hours that the turbines are off, when water from the weir pool is being released through the low-level pipes to maintain the minimum flow. Thus, significant aeration occurs at minimum flow as well as turbine flow. Although the aeration level at minimum flow is less than during turbine flow, shallow channel depths downstream from the weir during minimum create rapid natural aeration to high DO levels just downstream of the weir.

Chatuge Infuser Weir

The infuser weir below Chatuge Dam has also shown encouraging aeration results in recent performance tests. The infuser (Figure 2) is essentially a hollow, broadcrest weir with specially designed transverse openings in its crest that allow a series of water curtains to fall through to a plunge pool beneath the crest. This weir was designed to be capable of aeration efficiencies approaching that of the labyrinth at about half the construction cost, due to its compact size and shape that requires less concrete work. There are, however, some disadvantages relative to the labyrinth in backwater on the upstream turbine and debris accumulation.

The slotted infuser deck is attached to the downstream face of a conventional linear weir (Figure 2). In the case of the Chatuge weir, the weir portion is a timber crib filled with loose rock and lined with tongue-and-groove timbers along its upstream face to make it impermeable. The infuser deck openings are simply spaces between timbers that are overlain by a foot grating on the deck. These grated openings increase in size in the downstream direction to maintain equivalent flow in each slot as the head on each slot decreases. The timbers creating the blockages between slots are supported by concrete beams and columns.

Turbine flow overtops the weir onto the infuser deck, and the transverse slots in the infuser deck divide the total flow into a series of water curtains that plunge into the pool beneath the crest. Due to the foot grating that overlays the transverse openings, the infuser water curtains are turbulent compared to free overfall nappes, creating high nappe perimeter to flow ratios and increasing their aeration efficiency as impingement on the plunge pool occurs. The chamber beneath the infuser deck is ventilated using three open chimneys in the deck and two abutment vents that allow air to flow easily with minimal losses down under the deck and between the water curtains.

Laboratory tests of a developmental infuser with a 1.3 m drop height into a 1 m plunge pool resulted in transfer efficiencies of 35-55%, depending on deck length and opening area and the flow per deck area (Rizk and Hauser, 1993). Aeration tests of the prototype weir have shown that 65-70% of the oxygen deficit is recovered at turbine discharge flows (2.1m drop height). Figure 4 shows results of a recent aeration test using continuous DO monitors located in mid-channel upstream and downstream of the infuser weir.

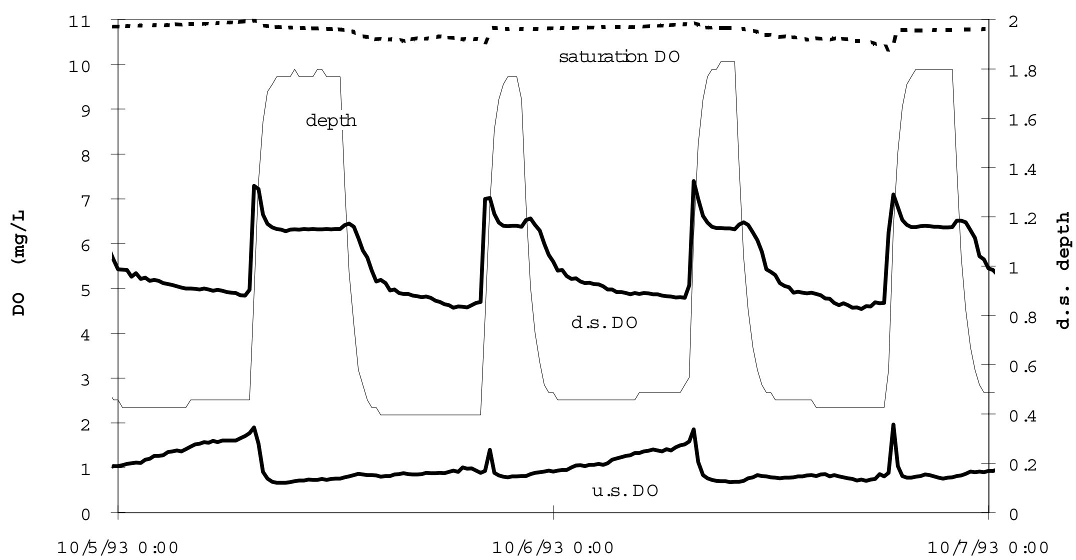

Figure 4. DO measurements above and below the Chatuge infuser

These results show that the 65-70% aeration during turbine flow reduces to between 30-40% of the deficit during the hours that the turbines are off, and water from the weir pool is being released through the low-level pipes for minimum flow maintenance. As at

South Holston, shallow channel depths cause the minimum flow to aerate rapidly shortly downstream of the weir.

Summary and Conclusions

For a given drop height (headwater to tailwater), labyrinth and infuser weirs can achieve similar aeration efficiencies in the turbine flow ranges studied. Due to its greater drop height (2.1 m at Chatuge compared to 1.4 m at South Holston, respectively), the Chatuge prototype infuser aerates a greater fraction of the deficit (65-70%) than the South Holston labyrinth (55-60%). However, on the basis of aeration per unit drop height, the South Holston labyrinth is more efficient than the Chatuge infuser (42% per m drop height at South Holston compared to 32% per m drop height at Chatuge).

The infuser is much more compact, however, and the capital cost of constructing an infuser can be considerably less than that of a labyrinth, depending on the crest lengths required. The required infuser crest length is roughly the channel width, while the required labyrinth crest length is that needed to yield a safe specific discharge (turbine flow divided by the safe specific discharge of 0.15 m^2/s). Weir heights depend on the aeration required, and if minimum flow is an objective, the weir height will also depend on the weir pool storage required to sustain the minimum between generating periods. In rough terms, infuser construction similar to that of the TVA design costs about $25,000 per m of crest length while labyrinth construction costs about $2,500 per m of crest length. Thus, if the required labyrinth length is greater than ten times the required infuser length, the infuser is likely to be less costly. The infuser at Chatuge was estimated to be about half to two-thirds that of a labyrinth designed for the Chatuge application. This cost comparison will change, however, for other sites, depending on the relative lengths of each weir that is required.

The infuser is capable of safely aerating much higher turbine flows than the labyrinth, because the labyrinth length (i.e., cost) required to maintain a safe specific discharge (0.15 m^2/s) becomes excessive at turbine discharges in the range of several hundred m^3/s. Operating costs with the infuser can be higher than the labyrinth due to its hydraulically less efficient infuser crest, which, depending on its proximity to the upstream dam, creates greater backwater on the turbine during generation and greater property inundation during flood flows. The infuser deck grating has a tendency to clog with leaves during the fall and other debris (tree branches, twigs) throughout the year, requiring frequent cleaning, while the labyrinth weir has operated with little or no maintenance.

The labyrinth, although more costly to construct, has a more efficient overflow, and can be located closer to the hydropower dam with less increase in backwater on the turbine. The labyrinth has little effect on property inundation during high flows because the weir tailwater increases more quickly than the weir headwater, causing submergence of the structure at lower weir head. The labyrinth is generally considered more aesthetically pleasing by the general public due to its extended waterfall length. Both of these prototype weirs will be monitored over time to further document performance and unique operating characteristics.

References

Avery, S. and P. Novak (1978); "Oxygen Transfer at Hydraulic Structures"; J. ASCE Hydraulics Division; November.

Hauser, G. E. (1991); "Full-Scale Physical Modeling of Plunge Pool Hydraulics Downstream of a Vertical Weir"; TVA Engineering Laboratory; WR28-1-590-153; Norris, TN.

Markofsky, M. and H. Kobus (1978); "Unified Presentation of Weir-Aeration Data"; J. ASCE Hydraulics Division; April.

Nakasone, H. (1987); "Study of Aeration at Weirs and Cascades"; J. Environmental Engineering; February, 1987.

Rizk, T. and G. Hauser (1993); "Chatuge Aerating Infuser Physical Model Study"; TVA Engineering Laboratory; WR28-1-17-101; Norris, TN; June.