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Modification of the Stilling Basin at Arthur R. Bowman Dam, Oregon to Reduce Dissolved Gas Supersaturation

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Abstract

A physical model study was conducted in the Hydraulics Laboratory of the US Bureau of Reclamation to develop a modification for the stilling basin at Arthur R. Bowman Dam, Oregon. Flow through the existing stilling basin generates supersaturated dissolved gas levels that exceed state standards. Alternatives stilling basin designs were considered. Resulting dissolved gas levels, modified energy dissipation, and potential structure and river bottom and bank erosion were evaluated.

Introduction

Arthur R. Bowman Dam is a 75 m high earthfill structure located on the Crooked River in central Oregon. The dam was constructed from 1958 to 1961. The spillway and outlet works share a hydraulic jump stilling basin (figure 1). The spillway is an uncontrolled chute. The outlet works includes a tunnel through the right abutment of the dam. Outlet works releases are controlled by high pressure slide gates located at mid-tunnel. Free surface flow occurs from the slide gates to the stilling basin. The outlet works discharge capacity is 93 m^3/s. The basin, which was developed from a previous physical model study, includes two interior walls that create a middle bay for the outlet works releases. Studies had shown that the interior walls were needed to prevent the outlet works flow from attaching to one or the other of the outer

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stilling basin walls. The basin was sized to control the maximum spill (230 m^3/s) spread over the full basin width. Thus the basin offers a pool which supplies excessive depth for the common outlet works releases.

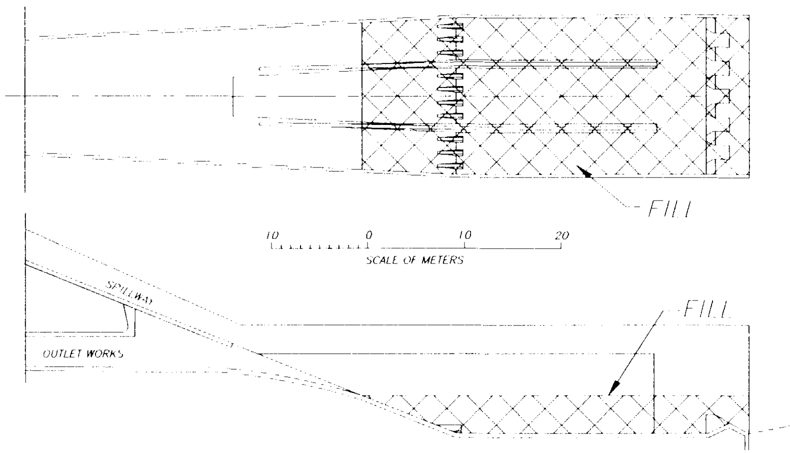

Figure 1. A. R. Bowman Stilling Basin

An analysis (Johnson 1975) of the gas transfer in the stilling basin, verified by limited field data, shows that high spring flows through the basin will cause dissolved gas supersaturation levels that exceed the Oregon standard of 105%. Depending on exposure duration, supersaturation levels of 110% to 115% can injure or kill adult trout (Weitkamp and Katz 1980). Other than high releases in the spring, discharges through the stilling basin are limited to minimum stream flow and small irrigation releases (approximately 6 m^3/s). These releases are not large enough to generate excessive supersaturation. The river below the dam is a quality trout stream with a flat gradient for an extended distance. Because of low turbulence, supersaturation levels created in the basin remain in solution and potentially have a negative impact on a long reach of fishery.

Rehabilitation Alternatives

Dissolved gas supersaturation results when release water with entrained air penetrates deep into a stilling basin.

The increased hydrostatic pressure that occurs at depth in the pool causes increased gas transfer. Alternatives to reduce or eliminate supersaturation include: preventing air entrainment, dissipating the energy in a shallower stilling basin, or agitating (as in a cascade) the flow downstream of the structure to free excess gas.

Previous observations show that air entrainment must nearly be eliminated to reduce gas transfer. These observations also show that with traditional hydraulic jump stilling basins it is difficult to develop schemes to exclude air entrainment. Thus, elimination of air entrainment was considered infeasible.

Use of a shallower, heavily baffled stilling basin that would maintain a hydraulic jump for discharges of up to 230 m^3/s was considered. Indications are that a projected maximum decrease of two meters in basin depth could be achieved. A two meter reduction in basin depth would not significantly reduce supersaturation. In addition, a baffled basin would be susceptible to cavitation damage.

Another option would be to construct a weir across the river channel some distance downstream of the stilling basin. The weir must have sufficient height to create a white water cascade. The gas stripping performance of such a structure is dependent on unit discharge (discharge per unit width of structure), vertical drop, and structure configuration (a single free fall vs a stepped cascade). For a specific structure design, as unit discharges increase, the structure may start to flood out, lose white water turbulence and lose effectiveness in generating gas transfer. Thus, weirs can be effective at stripping gas at low discharges but may have little influence at high discharges. To our knowledge, no structure of this type has been built for dissolved gas stripping. Structures have, however, been built and evaluated for reaeration (Task Committee on Gas Transfer 1990). The oxygen transfer characteristics do not directly apply to nitrogen stripping but do give an idea of weir height and unit discharge combinations that would be effective. For example with a 60 m long weir and a discharge of 30 m^3/s, reaeration data indicates that a 1.5 m drop would be required. A point to note is that the river has a fairly flat gradient for some distance downstream from the dam. The weir would have to be positioned 800 m or more downstream to prevent increased tailwater at the dam. The weir would increase water depth on the stream which would maintain elevated supersaturation (between the weir and dam) and possibly have negative influences on recreation and roads. Also the weir would effectively strip gas only with smaller discharges, which tend to not create problem levels of supersaturation. Thus use of a cascade was not further pursued.

A second potential basin modification would be to raise the basin floor by filling with mass concrete. No chute or baffle blocks would be included. The modified structure would function as a hydraulic jump stilling basin with smaller discharges. The basin would sweep out at major releases and thus function as a deflector, directing the release horizontally across the tailwater surface. Factors that would influence the modified basins performance include discharge, type of release (spillway vs outlet works), and the relative elevation of the basin floor and the tailwater surface. The relative elevation influences both the discharge at which the flow would sweep out and the characteristics of the sweeping flow. The flow may plunge off of the elevated basin, it may skim across the tailwater surface, or it may ride up on the tailwater and then plunge. With the objective of minimizing supersaturation, it is desirable to keep the flow with entrained air at or near the tailwater surface.

The performance of this type of structure is in part confirmed by prototype dissolved gas measurements taken at Kortes and Seminoe Dams, Wyoming and Island Park Dam, Idaho. All three have tunnel structures that release flow horizontally across the tailwater surface. The structures were observed operating at heads of 24 to 65 m and discharges of 30 to 180 m^3/s. Tailwater depths and potential for scour hole development are similar at all sites. Supersaturation levels ranging from 104% to 110% were observed. This compares to a level of 116% observed with the existing A.R. Bowman outlet works operating at a discharge of 42 m^3/s.

A drawback associated with this concept is the lack of controlled energy dissipation. At high flow, energy is largely dissipated outside of the stilling basin structure. In addition a strong directional surface flow down the tailwater channel results. Consequently bank and bottom erosion with downstream bar development are likely. Bank protection and bar removal after major releases may be required.

Historically, rock circulation in the stilling basin has caused ball mill erosion that has required dewatering and repair. By raising the floor of the basin a barrier to downstream rock transport into the basin is created and flushing of rock from the basin is expedited. The modified basin may generate back eddies immediately downstream from the basin. At higher flows this would cause ball mill erosion on the downstream face of the

basin. The modified basin would have a low potential for cavitation damage. Because of the numerous potential advantages of this concept, it was selected and pursued in detail.

Physical Model Study

The physical model study was used to evaluate the hydraulic action in the stilling basin and in the tailwater pool. The model study was used to select a basin floor elevation that generated skimming flow across the tailwater surface and thus minimized resulting supersaturation. The study also insured that the elevated floor did not restrict outlet works releases. And the study was used to develop a design that maintained a hydraulic jump in the basin for frequent discharges while keeping supersaturation levels within standards. Possible use of an end of basin treatment (to disperse the flow), basin self cleaning, and downstream bank and bottom erosion were also evaluated.

The study shows that if the floor of the basin was placed at elevation 935.4 m, 4.6 m above the current elevation, outlet works discharges of up to approximately 45 m^3/s will yield a hydraulic jump that is well contained in the basin. There is approximately a 70% probability that the 45 m^3/s discharge will be exceeded annually. Similarly, spills (which use all three bays of the stilling basin) of up to 110 m^3/s also generate hydraulic jumps that are well contained within the modified basin. A spill of 110 m^3/s is approximately the 100 year event. As discharges increase above these levels the position of the jump moves down the basin, dissipation within the basin is reduced, and velocities within the tailwater pool increase. The basin is near or at sweepout (the toe of the jump is at or downstream of the end of the basin) with an outlet works release of approximately 85 m^3/s or a spill of approximately 200 m^3/s.

Use of the empirical gas transfer theory (Johnson 1975) in conjunction with observed hydrodynamics from the physical model indicates that the Oregon state standard of 105% will not be exceeded for outlet works releases of less than 50 m^3/s. Outlet releases of 60 m^3/s will generate supersaturation levels of 107% and releases of 85 m^3/s will generate supersaturation levels of 116%. This compares to the unmodified structure performance of 108% at 30 m^3/s, 121% at 60 m^3/s, and 126% at 85 m^3/s. For spillway releases of 30, 60, and 85 m^3/s it is predicted that the modified basin will generate supersaturation levels of 111, 123, and 136%. This compares to predicted supersaturation levels of 137%, 147%, and 153% for the existing basin. At extreme discharges structural integrity, and not gas transfer, was of primary concern.

Iterations between velocities observed in the physical model and erosion and armoring predicted from the theory (Gessler 1965, Gessler 1970) were used to evaluate bottom and bank erosion that would result due to use of the modified basin. The potential for undercutting or ball mill erosion of the downstream face of the stilling basin structure was also considered. It was found that bottom and bank scour with armoring (which would not compromise the stilling basin) would result at larger discharges. The outlet works releasing 85 m^3/s will generate up to two meters of bottom and bank erosion. The spillway releasing 230 m^3/s will generate up to four meters of bottom and bank erosion. This scour with resulting deposition will require bar removal after major releases. Local eddy action at the end of the basin will cause ball mill concrete erosion. As a consequence, sacrificial mass concrete will be placed at the end of the basin to supply protection.

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