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**HYDRAULIC MODEL STUDIES OF  
ALTERNATIVES TO REDUCE SUPERSATURATION  
DOWNSTREAM OF YELLOWTAIL AFTERBAY DAM**

**BY**

**KATHLEEN L. HOUSTON**

**PAP-467**

INFORMATIONAL ROUTING

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DEC 14 1984

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Memorandum

To: Regional Director, Billings, Montana  
Attention: UM-210

From: Chief, Division of Research and Laboratory Services

Subject: Additional Model Studies of Yellowtail Afterbay Dam  
Sluiceway and Spillway - Recommended Alternatives for  
Reducing Supersaturation

GPO 852320

We have recently completed model studies investigating supersaturation reducing alternatives identified in your memorandum dated July 10, 1984, "Model Studies - Yellowtail Afterbay Sluiceway and Spillway - Pick-Sloan Missouri Basin Program, Montana."

The purpose of this memorandum is to provide recommendations for your selection of an appropriate alternative.

The recommended alternatives are:

- Raising the sluiceway basin floor
- Creating a cascade downstream of the sluiceway stilling basin

Neither alternative eliminates gas transfer - only a reduction in supersaturation levels can be achieved.

For a gas transfer analysis using a nitrogen supersaturation level of 120 percent the raised sluiceway basin floor will reduce supersaturation by 6 to 8 percent; the cascade by 10 to 13 percent.

Of these, the raised sluiceway floor would probably be the most economical to construct and have the least impact on the surroundings, while the cascade would be more effective in reducing supersaturation.

Further details on the alternatives considered and of the model test results are enclosed in the report titled "Hydraulic Model Studies of Alternatives to Reduce Supersaturation Downstream of Yellowtail Afterbay Dam" by Kathleen L. Houston.

Enclosures

Copy to: Project Superintendent, Hardin, Montana  
(with enclosure)

KLHouston:flh

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# Hydraulic Model Studies of Alternatives to Reduce Supersaturation Downstream of Yellowtail Afterbay Dam

by  
Kathleen L. Houston

## INTRODUCTION

Yellowtail Afterbay Dam is located on the Big Horn River below Yellowtail Dam and Powerplant. The purpose of the afterbay dam is to provide uniform flow in the river downstream by regulating the flows associated with peaking power generation at the upstream powerplant. Releases from the afterbay dam are made by a spillway, sluiceway, and canal. Under normal operating conditions, releases are made primarily from the sluiceway.

The Big Horn River is a renowned fishery. However, for some time, nitrogen supersaturation has been a problem in the river downstream of the afterbay dam. Recently, large numbers of fish have been injured or killed by high supersaturation levels. To date, attempts to alleviate this problem have been unsuccessful.

## PURPOSE

The physical model was used to evaluate the hydraulic performance of the following four alternatives:

- Raising the sluiceway basin floor
- Creating a cascade downstream of the sluiceway stilling basin
- Covering and submerging the bays downstream of the slide gates
- Installing new flow regulating radial gates downstream of the sluiceway chute

In addition to the physical model, each alternative was evaluated analytically for its potential to reduce supersaturation.

## CONCLUSIONS

The solution to the supersaturation problem at Yellowtail Afterbay Dam would be to allow no gas transfer; however, this cannot be achieved with any of the alternatives. Of the alternatives tested, the raised sluiceway basin floor and the cascade are the only hydraulically acceptable alternatives that will reduce the supersaturation levels. The raised basin floor will be less effective in reducing supersaturation, about 7 percent compared to 11 percent for the cascade, but may be less expensive to construct and more aesthetically acceptable.

## TEST RESULTS

The spillway was added to the existing dam and sluiceway model to allow total discharges up to 15,000 ft<sup>3</sup>/s for the remaining tests (fig. 1). Test conditions included sluiceway flows to 4,500 ft<sup>3</sup>/s and combined spillway and sluiceway flows to 15,000 ft<sup>3</sup>/s.

Raised Sluiceway Basin Floor. - Raising the sluiceway basin floor is a hydraulically feasible solution. The floor was raised 9 ft to El. 3148 and 4.5-ft high baffle blocks were placed 99 ft downstream of the gate structure. This configuration effectively reduced the flow submergence by half. The raised sluiceway basin floor design is shown on figure 2 operating at 4,200 ft<sup>3</sup>/s.

The hydraulic jump stayed in the basin for all flow conditions. During the winter more ice will form from stilling basin spray than has in the past.

Velocities and wave heights were measured at several locations, and ranged from 5 to 13 ft/s, and up to 1.6 ft (trough to crest), respectively. Both the maximum velocity and wave height occurred downstream of the sluiceway with the sluiceway discharging 4,500 ft<sup>3</sup>/s. This flow condition pulled material from the right bank, about 50 ft downstream of the sluiceway, diagonally across the 1:9 sloped riverbed towards the endsill. This might eventually cause buildup of material to the level of the sluiceway endsill. However, because no return flow into the basin was noted, the material would not move into the basin.

Combined spillway and sluiceway flows eroded the right bank downstream of the sluiceway basin. The erosion began about 100 ft downstream of the sluiceway and continued for 150 ft around the bend in the river. Erosion could probably be prevented by stabilizing the bank, perhaps with armor rock.

The supersaturation characteristics of the raised basin floor would be about the same as with the deflector plate design. The current worst case level of supersaturation (assumed to be about 120 percent) would be reduced by about 6 to 8 percent because the shallower water depth in the basin reduces the pressure on the entrained gas bubbles.

Cascade Downstream of the Sluiceway. - Both of the two cascades tested were hydraulically acceptable and would be effective in reducing gas transfer. The principle of the cascade is to remove gas by creating shallow tumbling flow over a rough surface. The cascades were located downstream of the original sluiceway stilling basin. Each cascade had a 300-ft crest length which extended about 200 ft downstream from the left sluiceway wall and then about 100 ft across the channel to the right bank (fig. 3). The cascades were formed with a vertical upstream face and sloped downstream face of 4-ft angular armor rock.

The first cascade was built with a crest elevation at El. 3171 to allow a 10-ft drop to the tailwater over a 2:1 sloped downstream face. This

cascade created a pool in the stilling basin that submerged the sluiceway slide gates eliminating bubble entrainment and thus eliminating gas transfer at this location. With this submergence, a maximum gate opening of 8 ft was required to pass 4,500 ft<sup>3</sup>/s at reservoir El. 3192. With a cascade of this height, the only possibility for supersaturation occurs where the flow enters the tailwater after tumbling over the cascade. To prevent supersaturation there, the tailwater depth should be made shallow by continuing the armor rock for about another 20 ft away from the toe of the cascade. This cascade is shown on figure 3 for a discharge of 4,200 ft<sup>3</sup>/s. This cascade would be a conservative and very effective design.

The crest elevation of the other cascade tested was lowered to El. 3166 leaving a 5-ft drop to the tailwater over a 3:1 sloped downstream face. With this cascade, submergence of the slide gates upstream was not sufficient to totally prevent supersaturation. The intermittent air entrainment observed in the model would result in supersaturation. However, the 3:1 sloped cascade face and shallow tailwater depth downstream of the cascade toe, should be sufficient to strip excess gasses that may have transferred at the gates. This design is less conservative, but should still be effective.

It is estimated that either cascade would reduce the supersaturation by 10 to 13 percent.

A final cascade alternative that was analyzed for its potential to reduce supersaturation, but not tested in the model, consisted of a cascade placed across the river at the location of the former cofferdam. As with the other alternatives, the crest length would be 300 ft. The cofferdam cascade would have the advantages and disadvantages associated with having to pass both the sluiceway and spillway discharges. When only the sluiceway is operating the cofferdam cascade would have a similar influence to the two cascades previously discussed. Therefore, when considering only sluiceway flow, the geometry of the cofferdam cascade should be similar to those previously described.

However, the influence of the added spillway discharge on the cascade performance and the influence of the cascade on spillway supersaturation must also be considered. The cofferdam cascade will raise the tailwater elevation at the spillway stilling basin. This will increase the pressure on the air bubbles entrained in the spillway flow and thus increase supersaturation levels that result due to spillway operation. A cascade with crest elevation at 3171 could be expected to increase supersaturation levels by 15 to 20 percent and a cascade with crest elevation at 3166 could be expected to increase supersaturation levels by 5 to 10 percent. The supersaturated gas will then be stripped or partly stripped by the cascade. The spillway releases however when combined with the sluice releases may yield total discharges greater than 4,500 ft<sup>3</sup>/s. Higher discharges will:

- Increase discharges per unit width of cascade and thus reduce the cascade gas stripping efficiency
- Raise the tailwater elevation below the cascade and thus increase supersaturation levels that would result at that location

- Increase flow velocity and momentum over the cascade and thus reduce the stability of the cascade structure
- In the extreme, flood out the cascade and completely eliminate its effectiveness

For discharges up to 4,500 ft<sup>3</sup>/s, the cascade would be very effective in stripping dissolved gas with resulting supersaturation levels primarily a result of the action at the toe of the cascade.

Covering and Submerging the Bays Downstream of the Slide Gates. - This alternative is not recommended because the present supersaturation level would not be reduced. The design included controlling with the existing slide gates, a sloping cover over the flow passages between the bays, and an increased tailwater (fig. 4). This design was not successful because reduced pressure under the cover near the gate structure drew air through the gate slots and under the cover regardless of the tailwater or submergence level. However, it appeared that aeration would not occur if flow control were shifted to the downstream end of the covers.

Installing New Flow Regulating Radial Gates Downstream of the Sluiceway Chute. - Two designs were investigated which involved installing another gate structure downstream of the existing gates. Neither alternative was acceptable because of air entrainment which would yield supersaturation levels higher than the raised sluiceway basin floor or the cascade.

The design included the existing slide gates with additional slide gates downstream in each bay, representing radial gates, which seated on the basin floor 13.5 ft downstream of the chute. To simulate the structural aspects of this alternative the pier widths were increased to 2.5 ft, raised to El. 3172 and extended to the downstream end of the basin.

Oscillations developed on the water surface between the existing gates and the new gates and in the basin downstream of the new gates. It was necessary to operate both the upstream and downstream gates to stabilize the water surface between the gates. These large oscillations were present throughout the basin and produced surface turbulence which caused gas transfer (fig. 5).

A cover was then installed between the two gate structures at El. 3165, the elevation of the maximum opening of the upstream slide gates. Controlling with the downstream gate created a positive pressure under the cover for all discharges and did not allow gas transfer from the upstream sluiceway gates. The oscillations and surface turbulence downstream of the simulated radial gates were still present. This flow condition created a new source of gas transfer downstream of the second gate structure which negated the effectiveness of the submerged upstream releases (fig. 6). Unsuccessful attempts, using baffle blocks and wave suppressors, were made to dissipate the surface oscillations. If this scheme is adopted, the downstream gates should be slide (not radial) gates with stoplog slots about 10 ft downstream of the gate to allow maintenance capability.



From the supersaturation standpoint, this alternative would be less effective than the raised sluiceway basin floor because the gas bubbles would be submerged to a greater depth.

#### SUMMARY

The ideal solution to the supersaturation problem below the afterbay dam would be submerged releases from the reservoir allowing no gas transfer. Unfortunately, of the alternatives tested the best that could be achieved was a reduction in the supersaturation level. The raised sluiceway basin floor or the cascade would be feasible alternatives. Of these, the raised floor would probably be the most economical to construct and have the least impact on the area, but the cascade would be more effective in reducing supersaturation. A cost estimate should be performed for these two alternatives.

#### ACKNOWLEDGMENT

The supersaturation characteristics of each alternative were analyzed by Perry L. Johnson.



Figure 1. - Overall view of the 1:18 scale Yellowtail Afterbay Dam spillway and sluiceway

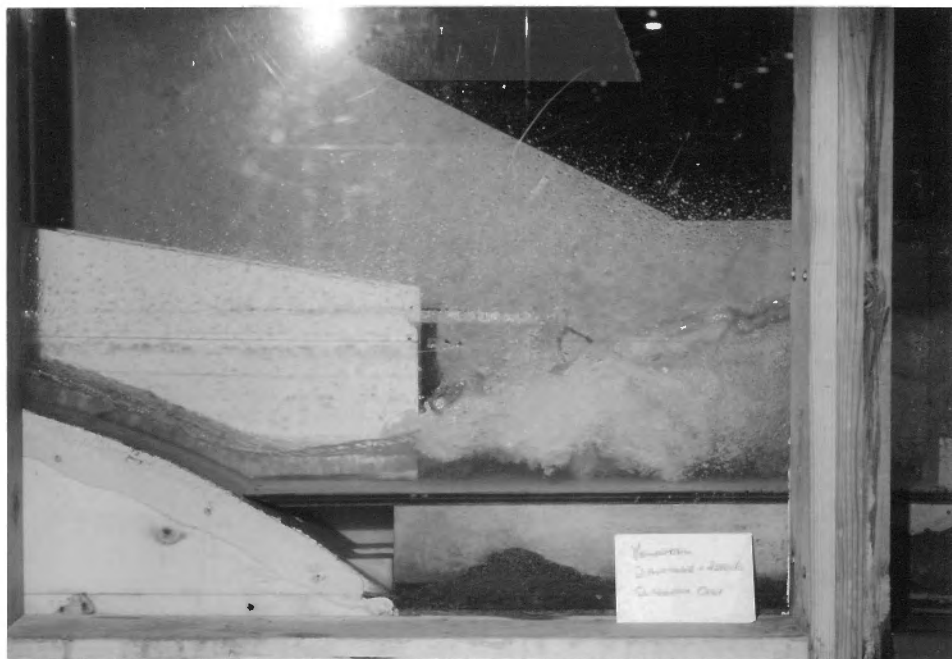


Figure 2. - The sluiceway with the raised basin floor operating at 4,200 ft<sup>3</sup>/s





Figure 3. - The cascade at crest elevation 3171, downstream of the sluiceway passing  $4,200 \text{ ft}^3/\text{s}$



Figure 4. - Sluiceway operation at  $4,200 \text{ ft}^3/\text{s}$  with covered bays downstream of the slide gates



Figure 5. - Sluiceway operation at 4,200 ft<sup>3</sup>/s with the second gate structure downstream of the original slide gates - note the turbulent water surface



Figure 6. - Sluiceway operation at 4,200 ft<sup>3</sup>/s with the area between the two gate structures covered