PAP-664

DISSOLVED OXYGEN ENHANCEMENT VIA TURBINE AND TAILRACE WEIR AERATION AT DEER CREEK POWERPLANT SUMMER 1994

by

Tony Wahl

November 8, 1994

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MEMORANDUM

To: Regional Director, Salt Lake City UT
Attention: UC-773

From: Tony Wahl, Hydraulic Engineer
Water Resources Research Laboratory

Subject: Analysis of Turbine and Weir Aeration Data from Deer Creek Powerplant - Summer 1994

The attached report summarizes the hydraulic analysis of turbine and weir aeration data collected at Deer Creek Powerplant during the summer of 1994. These data were collected by members of the Provo River Technical Subteam. Information contained in this report was provided in preliminary form to Jonathan Jones and Doug Young via electronic mail on November 4, 1994.

Dissolved oxygen (DO) enhancement was limited during 1994 by unusual weather and reservoir conditions. The need for high water releases through Deer Creek Dam during the aeration period led to low relative airflow rates. Benefits of turbine aeration were especially limited due to the low reservoir level that created turbine operating conditions that were unfavorable for drawing air into the turbines. Weir aeration was most effective late in the summer when discharges through the dam were decreased. Power losses due to the aeration activities were also reduced due to the unusual conditions. Estimated power losses during the 8 week aeration period were 4.8 MWh due to turbine aeration and 58 MWH due to the raising of the tailrace weir gates.

Although results from this summer's test were disappointing, turbine and weir aeration both have the potential to provide significant DO benefits in the future for the Provo River. Turbine aeration performance could be improved significantly under low reservoir conditions with the installation of hub baffles on the turbines. The report provides details on this option.

If you have any questions you may contact me at 303-236-2000, ext. 446.

Tony L. Wahl

Attachment

cc: Mr. Doug Young, U.S. Fish and Wildlife Service, 145 East 1300 South, Suite 404, Salt Lake City UT 84115
Manager, Provo UT, Attention: PRO-410 (Jones)
(w/att to each)

Blind copies to codes on attached sheet

bc: D-8500
D-8560 (Burgi, Wahl)
(w/o att to each)
D-8560 (PAP file)
(w/att)

WBR:TLWahl:flh:11-8-94:236-2000, ext. 446
(c:\wp\d3752\transmit.mem)

PEER REVIEW DOCUMENTATION

PROJECT AND DOCUMENT INFORMATION

Project Name Dissolved Oxygen Enhancement Below Deer Creek Powerplant WOID EKDXE

Document Report on Data Analysis of 1994 Powerplant and DO Data

Document Date November 4, 1994 Date Transmitted to Client ______

Team Leader Tony Wahl Leadership Team Member ______
(Peer Reviewer of Peer Review/QA Plan)

Peer Reviewer Perry Johnson Document Author(s)/Preparer(s) Tony Wahl

Peer Reviewer ______

Peer Reviewer ______

REVIEW REQUIREMENT

Part A: Document Does Not Require Peer Review

Explain ______

Part B: Document requires Peer Review: Scope: Full Document

Peer Review restricted to the following Items/Section(s): Reviewer:

REVIEW CERTIFICATION

Peer Reviewer - I have reviewed the assigned Items/Section(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer: [signature] Review Date: 11/7/94
Signature

Preparer: I have discussed the above document and review requirements with the Peer Reviewer and believe that this review is completed, and that the document will meet the requirements of the project.

Team Member: Tony L. Wahl Date: 11/7/94
Signature

Dissolved Oxygen Enhancement via Turbine and Tailrace Weir Aeration at Deer Creek Powerplant - Summer 1994

Prepared by:

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Introduction

This document discusses the powerplant and dissolved oxygen (DO) data collected during the DO enhancement efforts of Summer 1994 at Deer Creek Powerplant as they relate to powerplant performance and the effectiveness of passive turbine and weir gate aeration. Estimates of airflow rates, turbine efficiency reductions, and predicted DO increases are based on data collected during the 3-day test conducted in August 1993. Issues specifically addressed include:

- Estimated quantities of air drawn into the turbines
- Predicted and measured DO increases resulting from turbine aeration
- Estimated power losses caused by turbine aeration
- Measured DO increases resulting from aeration of flow over the weir gates
- Estimated power losses incurred due to the raising of the weir gates
- Recommendations regarding modifications that might improve future aeration efforts

Data Collection

Powerplant data were collected by the powerplant operators at 10:00pm each day. These data included discharge, reservoir and tailrace water surface elevations, turbine wicket gate positions, generator output, weir gate position (at downstream end of tailrace), and static vacuum pressures at the four air inlet assemblies. The air inlet assemblies were provided by Reclamation's Water Resources Research Laboratory in Denver, and consisted of a manual shutoff valve, a check valve to prevent backflow of water into the turbine pit, and piping necessary to connect to the turbines. Air inlet assemblies were attached in place of the vacuum breaker valve and to the snorkel tube piping on each turbine. To measure the static vacuum, powerplant operators temporarily plugged each air inlet and measured the vacuum using a gage supplied with the air inlet assemblies.

DO measurements were recorded on an hourly and daily average basis by sensors installed in the dam, in the tailrace immediately upstream of the weir gates, in the river just downstream of the weir gates, and at a location several kilometers downstream. The sensor in the dam measured the DO level in water withdrawn from the penstocks to feed the turbine bearing cooling-water system in the powerplant. Thus, this sensor provided the DO concentration for water exiting the reservoir and entering the powerplant. Figure 1 shows the DO concentrations measured in the dam (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 are also several 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).

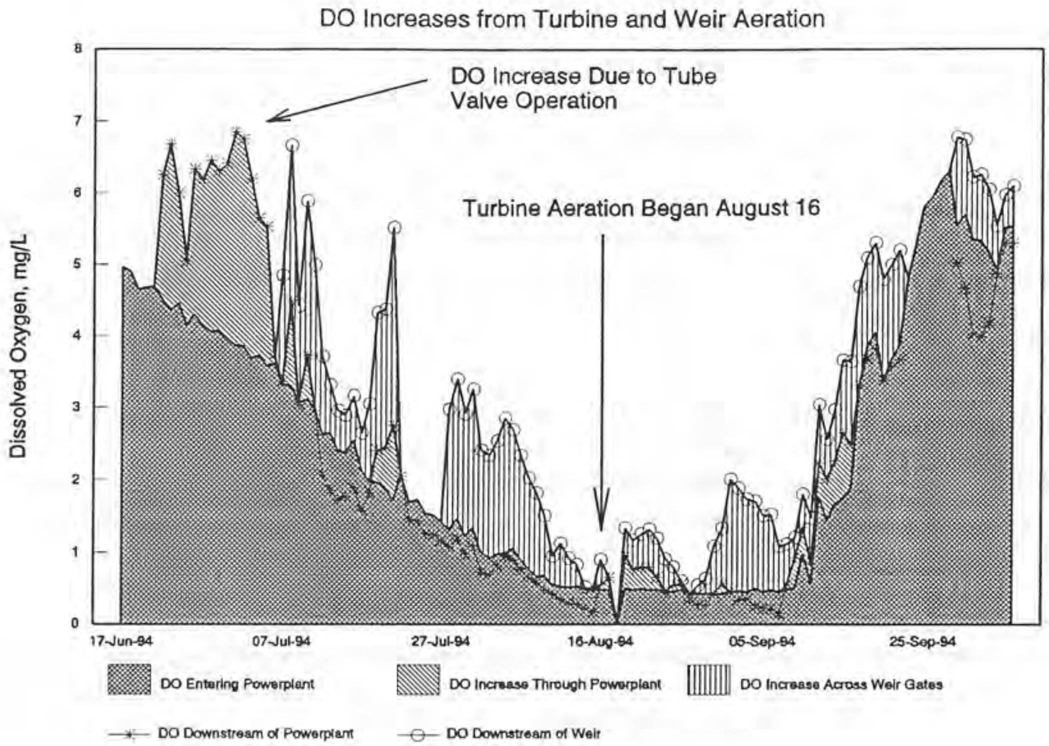

Figure 1. - DO concentration changes through Deer Creek Powerplant and over the tailrace weir gates (mean daily values). Note periods of missing and inconsistent data (DO downstream of the powerplant less than DO entering the powerplant).

Operating Conditions

Turbine aeration was initiated on August 16, 1994 on both turbines. Aeration was discontinued on September 30 on unit 2, and on October 10 on turbine unit 1. The weir gates were raised either 1.0, 1.5, or 2.0 feet from August 16 to October 1. The weir gates may also have been raised prior to August 16 for other purposes, but exact weir gate positions prior to August 16 were not recorded. Turbine discharges ranged from 260 cfs in early August (through each unit), to about 150 cfs in late September. In early October the discharge dropped as low as 130 cfs through only one unit. Total head across the turbines ranged from about 116 ft on August 16 to about 100 ft in late September. The rated head of the turbines is 120 ft and maximum head is 140 ft.

For comparison, total head across the turbines was nearly 140 ft during the August 1993 tests and discharges were varied from 94 to 283 cfs. Due to the higher reservoir head during the 1993 test, turbine wicket gate openings were about 7 to 10 percent higher for a given flow than those used during the 1993 test. Power outputs for a given flow rate were about 20 to 25 percent lower this summer due to the reduced reservoir head.

Turbine Aeration

Airflow - 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 compute estimates of airflow rates into the turbines. 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 25 to 50 scfm into each turbine, with an average of about 35 scfm per turbine. On a percentage basis, airflow rates ranged from 0.15 to 0.6 percent (volumetric percentage of waterflow). 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 without the use of compressors.

DO Increases - The low airflow rates led to disappointing increases in DO concentration through the turbines. Figure 2 shows the predicted and observed DO increases. The predictions are based on the results of the 1993 test and airflow estimates described above. The observed DO increases are based on daily average DO concentrations recorded in the dam and just upstream of the tailrace weir gates. The predicted DO increases (less than 0.2 mg/L for most of the aeration period) are much lower than the levels that could be reliably detected by the sensors. As a result there is poor agreement between the predicted and observed DO changes. The measurements indicate a reduced DO concentration downstream of the turbines in some cases, but this is most likely due to inaccurate measurements from one or more of the DO probes. Under no circumstances should it be possible to have a reduction in DO concentration due to turbine aeration.

Power Losses Due to Turbine Aeration - Power output from the generators was recorded throughout the summer, but because the turbines operated over a wide range of conditions, there were no baseline efficiency data to use for comparison in determining power losses due to aeration. The only baseline efficiency data available are those collected during the 1993 test at near maximum head and the manufacturer's predicted performance for the new turbines at the best-efficiency operating condition. Thus, power losses were estimated from the 1993 test data and the estimated airflow rates. Each 1 percent airflow was estimated to cause a 0.5 percent reduction in power output. Based on this calculation, total power losses due to turbine aeration from August 16 through October 10 were estimated to be 4.8 MWh.

Turbine Aeration Recommendations - Both turbines were operated with turbine aeration from August 16 to September 30. Due to reduced downstream flow requirements, only turbine unit 1 was operated after September 30. The test in 1993 showed that the air piping on the vacuum breaker of unit 1 was partially plugged. Thus, it would have been preferable to operate turbine unit 2 after September 30 rather than turbine unit 1. However, this would have had minimal impact this year since the reservoir had finished turning over by September 28, and DO levels after October 1 were already in the 5 mg/L range before entering the powerplant. The highest percentage airflow rates are achieved when the turbines are operated at low discharges, so the practice of operating both turbines as late in the season as possible (as was done this year) is beneficial from an aeration standpoint.

The primary reason for the low airflows and corresponding low DO improvements was the reduced reservoir level during 1994. The main source of airflow into the turbines is the vacuum breaker system. Air is drawn in under the headcover and enters the turbine through ports in the crown (the top flow surface) of the turbine runner. As the net head on the turbines decreases, flow conditions within the turbines change. At maximum head the flow tends to separate from the crown of the

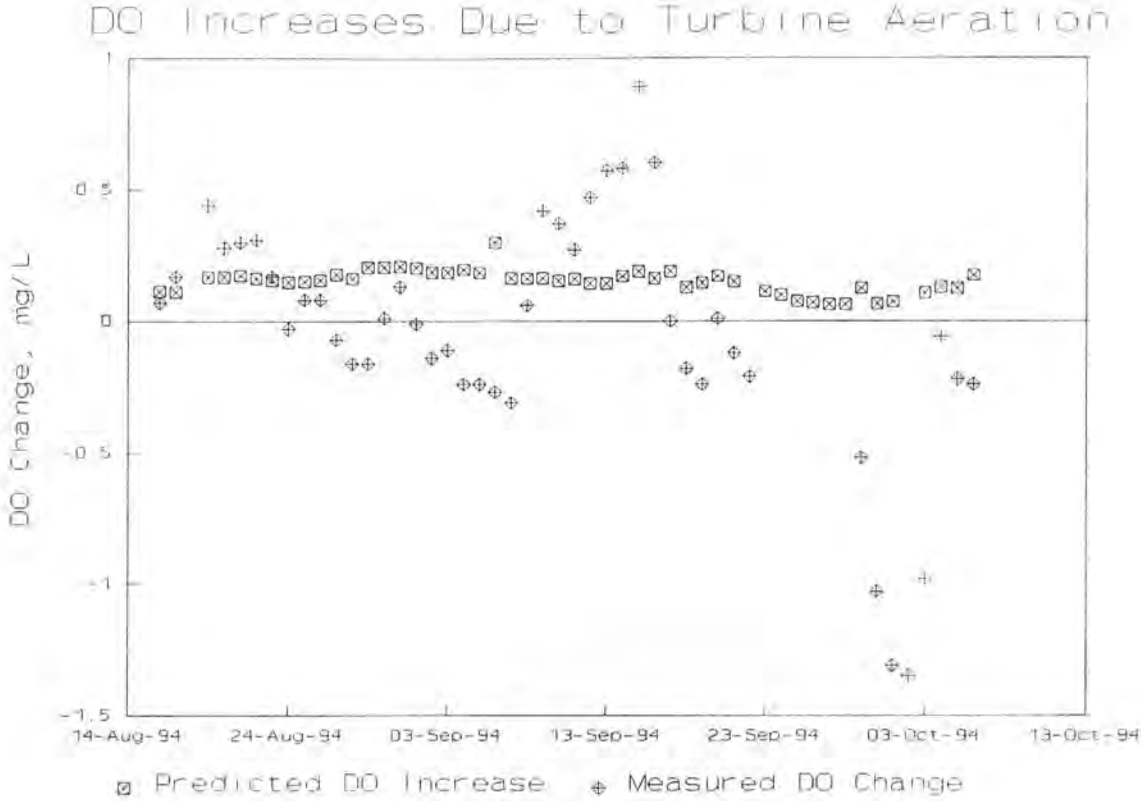

Figure 2. - Predicted and observed DO changes due to turbine aeration.

runner, creating a low pressure region at the crown that helps draw air into the turbine. As the head decreases the flow separation decreases, pressures at the crown go up, and the airflow decreases.

This behavior is similar to that observed 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 has observed that the Cherokee units draw large quantities of air at maximum head conditions, but draw little or no air as the reservoir drops toward its minimum level. At Cherokee, TVA has installed hub baffles (deflectors) that create a small separation zone on the crown of the runner in the immediate vicinity of the air ports. The baffles maintain low pressures and high airflow rates over the full range of operating heads. Figure 3 shows a typical hub baffle installation. 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. TVA has measured a 0.4 percent efficiency loss due to the baffles at their Norris Powerplant. TVA has an extensive program to install aeration baffles at many of their powerplants.

To improve aeration of the turbines at Deer Creek for the low reservoir conditions experienced in 1994, baffles could be added to the units. The process is generally straightforward, requiring a day or less of labor for the actual baffle installation. Baffles are welded onto the crown immediately upstream of the air ports (7 ports on each unit). 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.

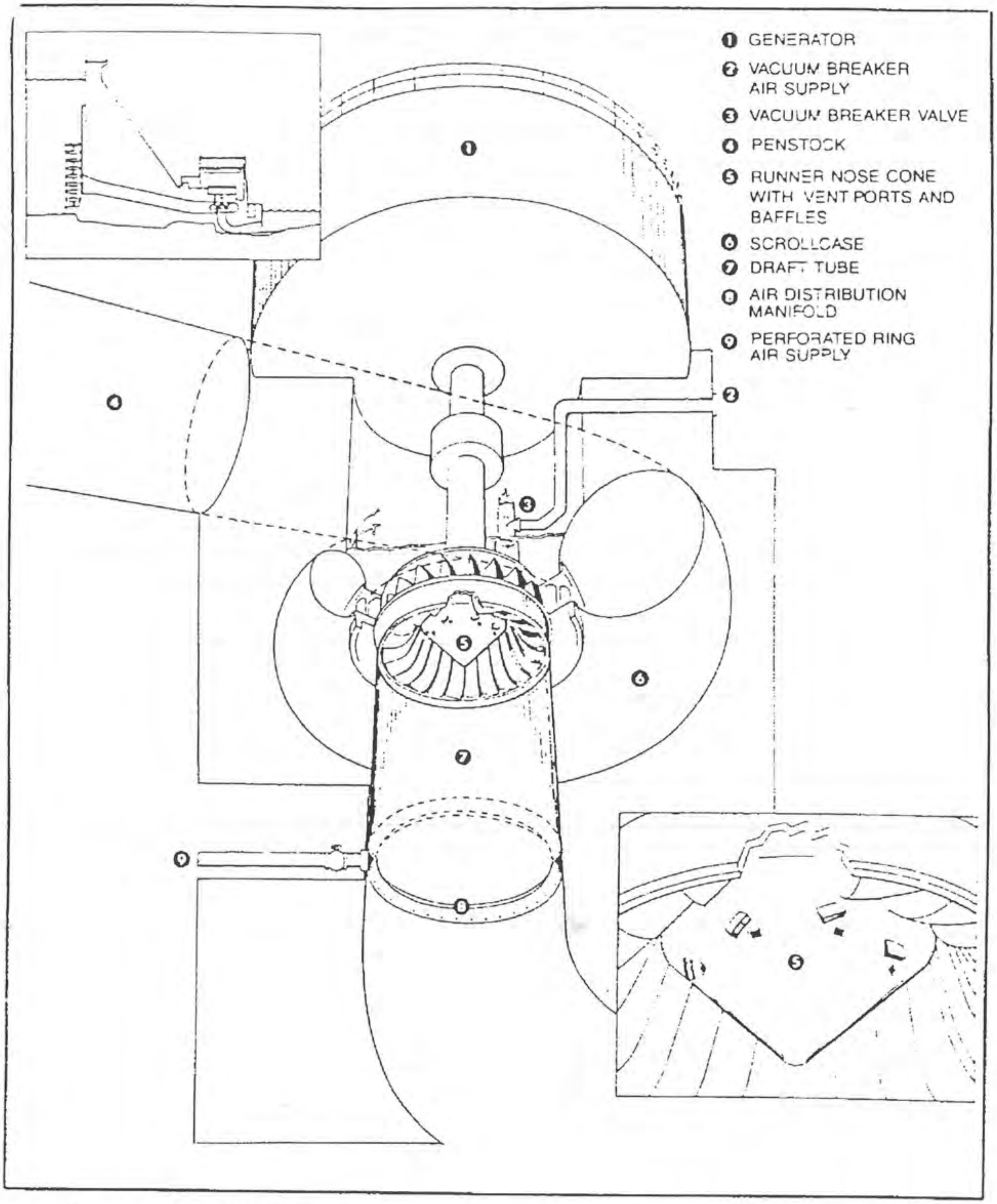

Figure 3. - Typical hub baffle installation.

Weir Aeration

DO increases across the weir gates were in the range of 0 to 2 mg/L with the largest DO increases occurring as the total powerplant discharge decreased. The primary factor influencing DO uptake across the weir gates is the amount of air entrained by the flow as it drops over the gate leaf and plunges into the pool downstream of the gate. Past research has shown that the perimeter of this jet where it enters the downstream pool is an important factor in determining the quantity of air entrained. For this case, the length of the weir is constant so the perimeter of the jet varies only with the thickness of flow over the weir. Since the flow thickness is much less than the weir length, the perimeter of the jet and the total quantity of entrained air should remain relatively constant as the flowrate over the weir changes. Thus, one would expect that the relative amount of entrained air would increase as the total discharge decreases. Figure 4 confirms this hypothesis for the period in which the gates were raised and there are both discharge and weir gate position data (Aug. 16 to Oct. 1). The aeration efficiency (the DO increase as a percent of the initial deficit from saturation) increases as the discharge over the gates decreases.

Raising the weir gates causes power generation losses due to the reduction of net head across the turbines. Power losses were assumed to be proportional to the reduction in head. For the period from August 16 to October 1 the estimated total power loss is 58 MWh.

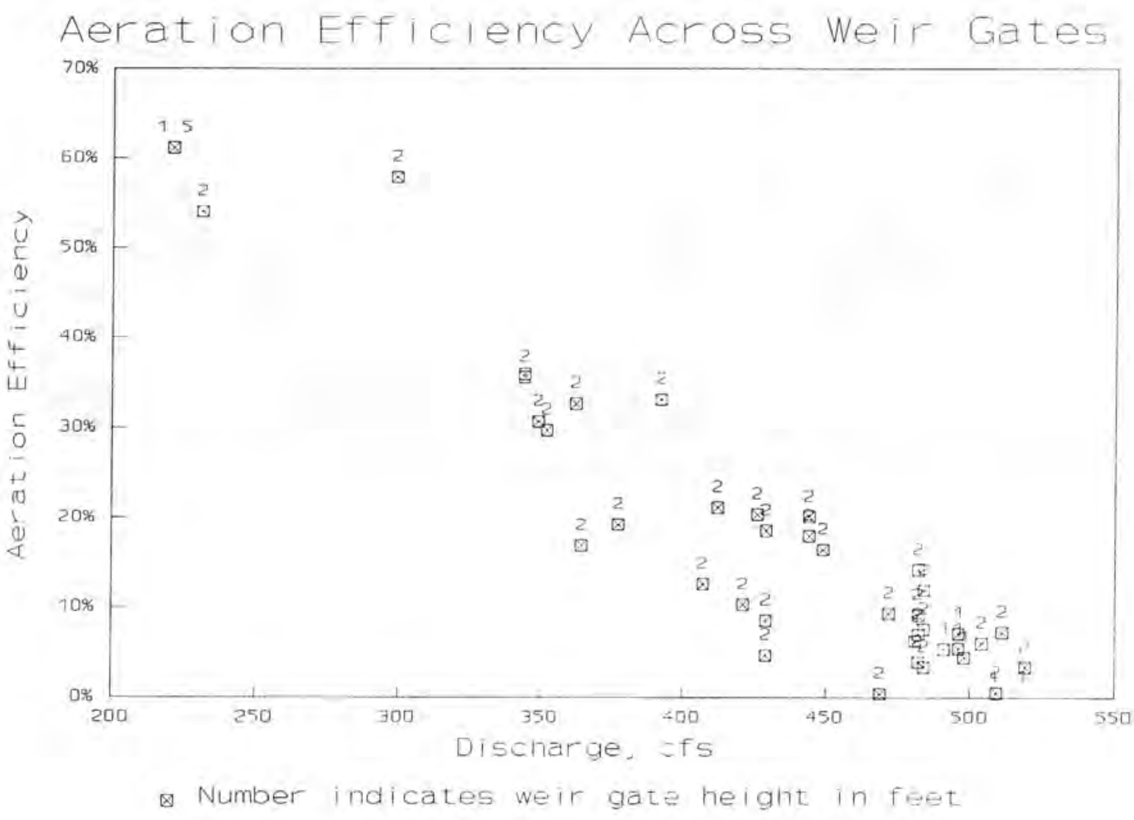

Figure 4. - Weir aeration efficiency versus discharge.

Conclusions and Recommendations

- Passive turbine aeration had a minimal impact on DO levels downstream of the powerplant due to low reservoir head throughout the summer that reduced the airflow into the turbines.

- Passive turbine aeration could still be effective under higher reservoir conditions, similar to those experienced during the 1993 test.

- In future turbine aeration efforts unit 2 should be operated whenever only one unit is needed to meet downstream discharge requirements. When possible, to obtain maximum DO increases, both turbines should be operated at low discharges rather than operating one turbine at high discharge.

- To improve future turbine aeration, especially during years with low reservoir levels, the installation of hub baffles on the turbines should be considered. Hub baffles would be beneficial for both passive or active turbine aeration. Hub baffles would produce a year-round power loss (likely less than 0.5 percent) in addition to power losses associated with aeration. Before installing hub baffles or implementing an active aeration program, every effort should be made to remove the obstruction in the air line of the vacuum breaker system on turbine unit 1.

- The height of the weir gates did not appear to have a large influence on the DO increase achieved across the gates. In future efforts the weir gates could probably be lowered partially to reduce power losses. Testing at the site may identify an optimum weir gate position that balances DO benefits and power losses.

- Under the reservoir and flow conditions experienced this summer, weir aeration was much more successful than turbine aeration, although power losses due to weir aeration are also much greater. With conditions similar to those experienced during the 1993 test weir aeration and turbine aeration were about equally effective, with turbine aeration causing about one-half as much power loss as weir aeration.

- Power losses due to aeration activities could not be determined definitively. However, estimated power losses for the period from August 16 to October 10 were 4.8 MWh due to turbine aeration and 58 MWh due to the raising of the tailrace weir gates.