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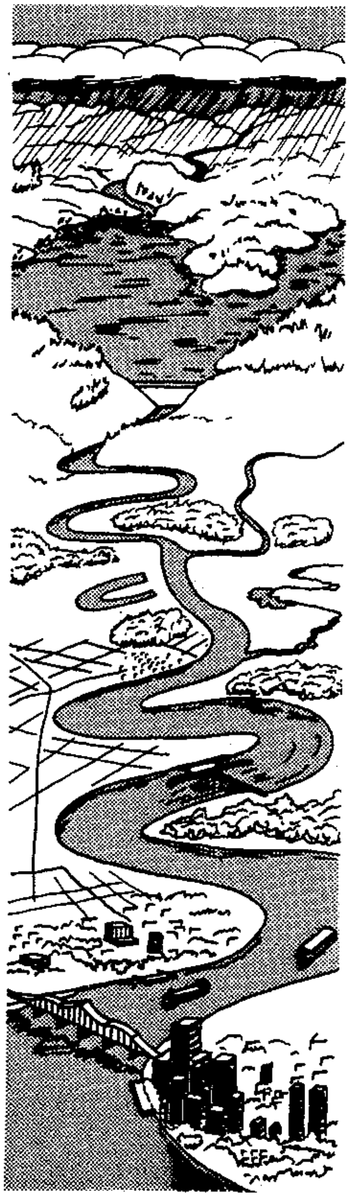

WOTS/ Water Operations Technical Support

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Simultaneous Multiple-Level Withdrawal for Reservoir Release Water Quality Regulation

by
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Background

Many lakes and reservoirs stratify thermally during the warmer months. A reservoir's surface waters, which receive more heat than its bottom waters, become lighter and tend to remain at the surface. Density stratification has the effect of limiting vertical movement of water within the reservoir since vertical mixing in such a stratified environment requires that buoyant forces be overcome. This limited vertical mixing often results in stratification of other water quality constituents as mixing between layers is reduced.

Multi-constituent, vertical stratification presents a variety of water qualities in the vertical water column of a reservoir. By taking advantage of the limited vertical movement induced by the stratification, a specific quality of water often may be selected from the variety of qualities and released through the reservoir outlet works while not withdrawing from the entire depth of the pool. This technique is very common in reservoir release quality regulation and is termed "selective withdrawal."

Sometimes, one vertical level of withdrawal from a stratified pool is adequate, but two or more levels are often needed. This need may arise when single-level operation cannot withdraw the desired quality and quantity of water. Traditionally, simultaneous multiple-level withdrawal has been accomplished by using individually controlled dual wet well outlet structures like the one depicted in Figure 1a. One level of withdrawal is selected in each wet well and the two qualities are mixed in the release conduit and stilling basin downstream of the individual wet well service gates.

Dual wet well, dual flow control operations are not always possible, however. Situations arise in which multiple levels of withdrawal are desired but individual flow control for each level is not possible or not practical. For example, the addition of hydropower to existing outlet structures has become an attractive source of energy in recent years. In many cases, this process involves removal of flow control from the wet well service gates and establishment of flow control at the turbine downstream, as seen in Figure 1b. In this situation, and in a similar situation involving selective withdrawal addition to existing hydropower facilities, individual flow control for each of multiple withdrawal levels is not possible. In other instances, feasibility may prevent the establishment of

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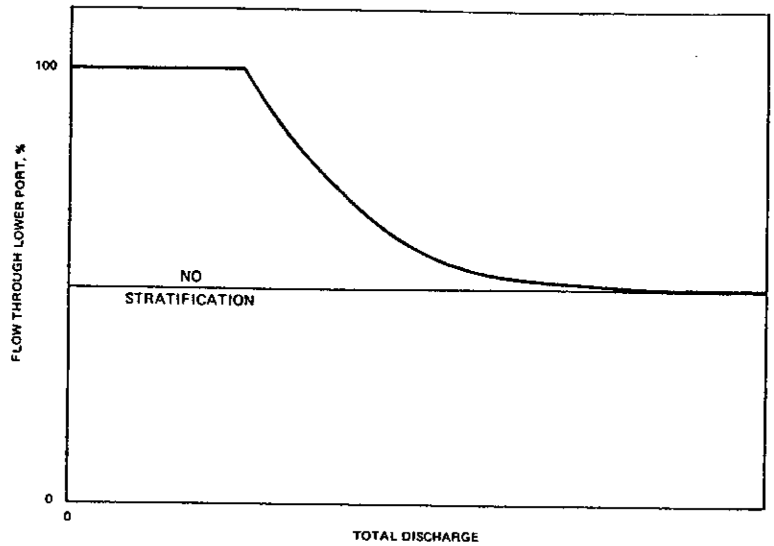

Figure 2. The effects of density for one stratification pattern and one port configuration with varying discharge

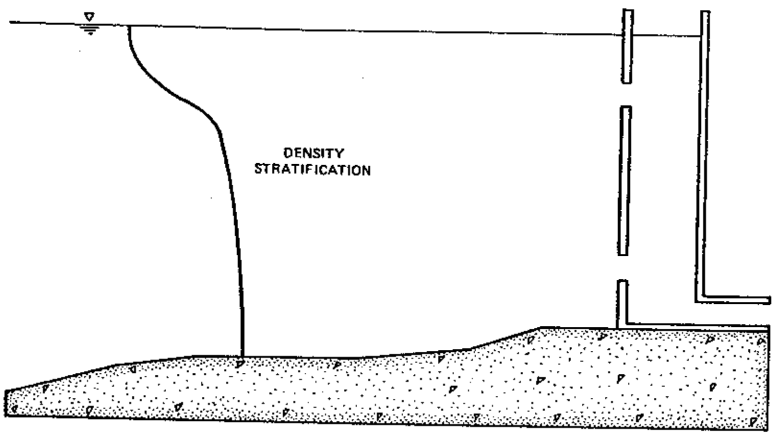

Figure 3. Two port, single wet well intake structure

loss is important in describing the blending process. Therefore, the prospect of using partial port closure (port throttling) to control head loss, and thereby blending, was also investigated. Such throttling was found to provide expanded control over the blending process by altering the flow ratios between withdrawal levels.

Data have been collected from several laboratory and prototype sources. Among these data sources is a 1:20-scale physical model. The theoretical description for single wet well blending was applied to the results of several tests using this model. The theory well accounted for the influences of density by accurately predicting discharge through the lower port of a two-port configuration over a wide range of discharges. Figure 4 demonstrates the close agreement between observed and predicted flow rates through the lower ports.

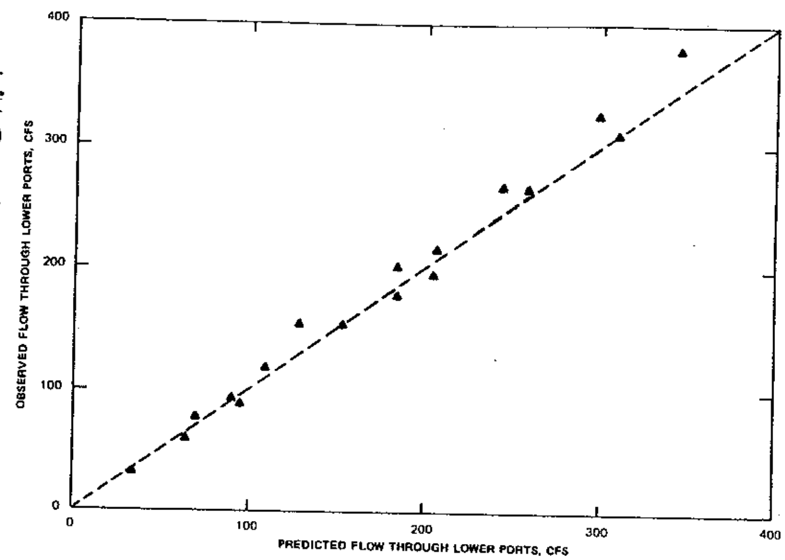

Figure 4. Predicted versus observed discharge through the lower ports in the 1:20-scale physical model

Summary and Conclusions

A theory for single wet well blending has been developed that predicts individual port flows for any stratification pattern and any number of simultaneous levels of withdrawal. From initial comparison of the theory to observed data, the limitations of the theory appear to be minor. The theory potentially will provide a method for predicting release water quality and developing improved strategies for blending operations that previously have been performed on a trial and error basis. Once the theory has been further generalized to describe the dual wet well, single flow control problem, potentially adverse impacts of hydropower addition to existing, dual wet well, dual-control outlet works will be predictable and the adverse effects more easily manageable.

Head loss is the driving mechanism for blending. The generation of head loss by partial port/gate closure adds a great deal of flexibility to blending operations. However, creation of increased head losses is contrary to hydropower purposes and, under extreme conditions of port throttling, head loss potentially can become significant. The result could be a situation that requires compromise between water quality and hydropower interests. Throttling of the port gates is not mandatory in blending operations but often may be desirable from a water quality management perspective.

References

Brater, E. F., and King, H. W. 1976. *Handbook of Hydraulics*, McGraw-Hill, New York.

Howington, S. E. 1986. "Simultaneous Multiple-Level Withdrawal Through Single Wet Well Structures for Downstream Water Quality Maintenance," *Proceedings: CE Workshop on Reservoir Releases*, 28-30 October 1986, Atlanta, Georgia, also to be published as a Miscellaneous Paper by the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

ENVIRONMENTAL AND WATER QUALITY OPERATIONAL STUDIES

This bulletin is published in accordance with AR 310-2. It has been prepared and distributed as one of the information dissemination functions of the Waterways Experiment Station. It is principally intended to be a forum whereby information pertaining to and resulting from EWQOS can be rapidly and widely disseminated to Corps District and Division offices as well as other Federal agencies, state agencies, universities, research institutes, corporations, and individuals. Contributions of any type are solicited from all sources and will be considered for publication as long as they are relevant to the objectives of EWQOS, i.e., to provide new or improved technology to solve selected environmental quality problems associated with Civil Works activities of the Corps of Engineers in a manner compatible with authorized project purposes. This bulletin will be issued on an irregular basis as dictated by the quantity and importance of information to be disseminated. Communications are welcomed and should be addressed to the Environmental Laboratory, ATTN: J.L. Mahloch, U.S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, Mississippi 39180-0631, call AC 601/634-3635.

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