CURRENT STUDIES RELATIVE TO RESERVOIR OPERATION IN THE INTEREST OF WATER QUALITY

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Although water quality is not definitive since each user has his own standards and any one user may have an entirely different attitude toward the quality of water which he receives for use and that which he wastes, the public has become increasingly aware of the term water quality as it applies to personal consumption and recreational use. Public Law 660 as amended by the Federal Water Pollution Control Act Amendments of 1961 - (PL 87-88), the Water Quality Act of 1965 - (PL 89-234), and the Clean Water Restoration Act of 1966 were significant steps toward an accelerated national attack on pollution and enhancement of the quality and value of our water resources.

In a broad sense, reservoir operation in the interest of water quality has been common practice throughout history; although, operation in the past has been governed primarily by other single or multiple purposes for which the projects were constructed. The need for increased efforts to obtain optimum use of our water resources becomes more evident with the growth of population and industry and the increased demands on our water resources.

Solar energy and the process of photosynthesis generally assist in supporting the oxygen content of impounded water. Circulation induced by wind, convection, and the flow of water entering and withdrawn from the impoundment assists in distributing such water to all parts of the reservoir. However, circulation may be restricted by the presence of a thermocline, a layer of sharp temperature difference, and the corresponding stratification of the reservoir. Stratification due to chemicals or dissolved solids and turbidity or suspended solids is possible also in fresh water reservoirs. Water below the thermocline or interface is generally void of sunlight due to the depth and/or turbidity involved, and its oxygen content is diminished by the decay of settling matter. Products of reduction will accumulate and, in time, the water may acquire an unpleasant taste and odor or become unfit for supply. Thus, the thermal stratification becomes a chemical stratification also. No attempt is made herein to discuss the use and/or effectiveness of pneumatic and hydraulic methods of preventing stratification by inducing circulation or the resulting effect on the quality of impounded waters. The need for increased knowledge regarding water quality characteristics of reservoirs, the mechanics of stratified flow in reservoirs, and the mechanics of selective withdrawal to permit prediction of the changes in water quality of proposed reservoirs during the planning stage, the design of structures for selective withdrawal, and the method of operation required for effective control of both the thermal and chemical qualities of releases from stratified reservoirs is apparent. This is particularly true in the case of reservoirs and multi-purpose projects presently in the planning and design stages within various offices of the U. S. Army Corps of Engineers in which specific requirements relative to the thermal and chemical quality of releases are desired.

Investigations of reservoir water quality are being conducted by various private and governmental agencies throughout the United States, as is being done in a local cooperative effort of the Department of Biology of the University of Mississippi, the Mississippi State Board of Health, and the U. S. Army Engineer District, Vicksburg, to observe water quality characteristics of reservoirs and the stream flow upstream and downstream of the reservoirs throughout the Yazoo River Basin. Factual data obtained to date in the Yazoo River Basin, Mississippi, and the Ouachita River Basin, Arkansas, are presented in a U. S. Army Engineer District, Vicksburg, report, Reservoir Water Quality Investigations, dated March 1967. Although the investigations to date have covered too short a period for proper evaluation of the program, the formation of distinct thermoclines in the spring and their breakup in the fall were observed in the Sardis, Enid, and Grenada reservoirs. The Arkabutla Reservoir is shallow, and no distinct thermocline has been observed during the investigation. With regard to the Sardis Reservoir, the relatively short period of dissolved oxygen data does not permit much analysis, but there is indication that short periods of minimum oxygen content can be expected in the hypolimnion or lower depths. The content of dissolved oxygen in the released water was well above the minimum standard, and the analysis of water samples by the Mississippi State Board of Health showed no indication of problems in stored or released waters. Air entrainment during release of flows is indicated as the dissolved oxygen content observed downstream of the structure is greater than that observed in the reservoir.

Results presented in the Annual Report on the Coralville Reservoir Water Quality Study dated January 5, 1966 for the water year October 1, 1964 to September 30, 1965, by D. B. McDonald and R. D. Schmickle of the University of Iowa Department of Civil Engineering, indicate to some extent the effect of the operation of a relatively shallow flood-control reservoir on the chemical and biological characteristics of the Iowa River. At conservation pool level, 63 percent of the reservoir has a depth less than 10 ft. This results in a close association between the zones of photosynthesis and decomposition, with an accompanying increase in biological productivity. Reduced dissolved oxygen contents were observed in the deeper waters of the reservoir on several occasions during the summer months. Although a true thermal or chemical stratification did not develop within the reservoir, periods of partial stratification were observed with resulting oxygen depletion of the deeper waters. The periods of partial stratification were always transient and disappeared quickly as wind action, river flow, and possibly other factors resulted in complete mixing of the waters within the impoundment. Although the effects of the impoundment on the quality of the Iowa River water tended to be favorable during the reported water year, it was pointed out that the development of an extensive bloom of undesirable algae within the shallow areas of the reservoir, with subsequent reduction in water quality of the river downstream, is a distinct possibility during a combination of warm days, low inflow, and proper environmental conditions. In time, continued investigations of the physical, chemical, and biological characteristics of existing streams and reservoirs will provide data regarding the mechanics of stratified flow in reservoirs and knowledge sufficient for the development of accurate ways and means of predicting the seasonal variation in the quality of future impoundments and the realization of the idealistic optimum use of our water resources. Such data upstream and downstream of existing regulating structures will be useful in evaluating the effectiveness of various structures and means of regulation on reaeration and general improvement of our water resources. In reality, there are many unknowns relative to the physical, chemical, and biological characteristics of existing streams and reservoirs and the effects of various multi-purpose requirements on the quality of impounded water. These can be determined only by continued study of the general characteristics of existing streams and reservoirs.

Planners and designers are faced with the problem of predicting the quality of impounded water and means of effectively controlling the thermal and chemical quality of releases from stratified reservoirs passed through powerhouses, spillways, and outlet works. Information for predicting general water quality characteristics and the effectiveness of various structures in selectively withdrawing releases from various levels of a reservoir are urgently needed at present for the design of multi-purpose projects in which specific thermal and chemical requirements of the releases are desired based on existing and/or future needs.

The U. S. Bureau of Sport Fisheries and Wildlife have indicated that releases for maintaining the existing or desired fish population downstream of a project should be of temperatures suitable for the particular species involved and should contain a dissolved oxygen content of not less than 5 mg/liter. To ensure that these requirements can be met most of the time, multi-level intake structures and submerged weirs for selective withdrawal purposes are proposed for several multi-purpose projects being designed in various offices of the Corps of Engineers. On certain projects, selective withdrawal is desired not only during periods of low flow releases in late summer and early fall when the reservoirs may be highly stratified, but also during reservoir flushing operations where release of relatively large quantities of bottom and surface water is desired. Certain projects require relatively high rates of outflow during normal operation, and the blending of water from intermediate levels with surface water will be necessary for successful operation. The desire to release good quality water regardless of conditions, including discharge, will require a procedure for monitoring the characteristics of water within the reservoir as well as that withdrawn. Therefore, knowledge of the pattern of flow to be expected in the immediate and upstream vicinity of various intake structures, and the effect on withdrawal of the size, shape, and vertical spacing of multi-level openings, is desired to permit prediction of the level of the reservoir where releases can be anticipated and the optimum location for fixed monitoring stations within the reservoir. Evaluation of the effectiveness of submerged skimming weirs or thermal barriers in preventing the intrusion of cold water void of dissolved oxygen into powerhouse intakes is of primary concern also.

Obviously, the U. S. Army Engineers Waterways Experiment Station (WES) is interested in developing model techniques for solution of these and other problems associated with the mechanics of stratified flow and selective withdrawal. During August 1966, the Director of WES approved an In-house Laboratory Initiated Research Project to assist in accomplishing this task. In addition, the Office, Chief of Engineers, and the Philadelphia and Savannah Districts have recently approved model studies concerned with the mechanics of selective withdrawal from stratified reservoirs for the purpose of assisting in the design and evaluation of certain proposed structures.

A continuing review of literature was initiated during September 1966. Various ways of generating stratification or density differentials by the addition of dissolved and/or suspended solids or by means of temperature differentials were considered, and the present consensus of engineers at WES is that the use of dissolved solids (salt) is the most practical method of generating density differentials. Upon completion of investigations concerned with the development of model techniques and instrumentation, tests of a generalized nature will be undertaken to determine the characteristics of the withdrawal zone upstream of various-shaped orifices for various conditions of stratification in order to develop generalized equations for use in predicting the quality of water discharged through similar openings in prototype intake structures. Initial tests will be conducted with a two-layer fluid system utilizing fresh and salt water to determine the maximum or limiting discharge or velocity of fresh water required to initiate withdrawal of salt water through an orifice. The variables to be investigated include the relative density of the fresh and salt water, orifice shape, the elevation of the orifice relative to both the bottom and surface of the reservoir, and the level of the interface relative to that of the orifice. Similar investigations can be conducted to determine the limiting conditions required to initiate withdrawal of the lower denser fluid over a submerged weir for the purpose of evaluating the effectiveness of such a scheme in preventing the release of water from the lower levels of a reservoir through a low-level intake of a powerhouse or outlet works. Eventually, the pattern of flow and characteristics of selective withdrawal for stratification conditions involving two or more distinct layers of fluid and various linear density profiles will be investigated.

Although there are, presently, many unknowns relative to the mechanics of flow within and selective withdrawal from stratified reservoirs, research in this area is dynamic, and the forthcoming results of both model and prototype observations should be most enlightening.

The opinions expressed in this paper are those of the author and do not necessarily reflect the opinion of the Corps of Engineers.