Reservoir Water Quality Control

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With the exception of the Tennessee River the Corps of Engineers has extensive water resource development and management responsibilities in the Ohio River basin. Overall development and management objectives include flood control, navigation, water supply, hydropower, flow augmentation, water quality control, recreation, and fish and wildlife. These objectives are being met by meshing the operation of 56 tributary storage reservoirs. In addition, large systems of lock and dam structures maintain navigation pools or channels along the main stem and larger tributaries. Many of the navigation pools are significant in terms of water supply and hydropower.

The Ohio River is formed by the confluence of the Allegheny and Monongahela rivers at Pittsburgh, Pennsylvania. It flows 1580 river km to the west to join the Mississippi River at Cairo, Illinois. The basin drains 528,000 km² and lies within four major physiographic divisions: the valley and ridge province, the Appalachian plateau, the interior low plateau, and the central lowlands. The topography is quite diversified and is graduated between the mountains to the east and the low plateaus to the west.

Most of the basin is underlain with two basic groupings of sedimentary rocks: coal measures and a series of calcareous sediments. The coal measures form the Appalachian plateau in the eastern third of the basin and underlie parts of the central lowlands to the west. They consist of a great series of sandstones and shales containing many important coal beds. The calcareous rocks, consisting of limestones and shales, underlie a broad belt in the central part of the basin. Much of the drainage to the north of the Ohio River below Portsmouth, Ohio, has been glaciated.

The climate of the basin is temperate. Rainfall and runoff tend to be high in winter and spring and low in summer. Average annual precipitation varies from 129.5 cm at the southwestern boundary to 109.2 cm in the extreme northeast and from 154.4 cm in the extreme southeast to 94.0 cm in the northwest. Storms have occurred with precipitation averaging 16.51 cm in 48 hours over 95,800 km². On the other hand, monthly rainfalls averaging as low as 4.32 cm have persisted for 6 months at a time over much of the basin. The average annual discharge furnishes about 60% of the Mississippi River flow at the point of confluence and about 45% of the flow at New Orleans, Louisiana.

Approximately one third of the area is used for intensive agriculture. Livestock, corn, soybeans, small grain, and tobacco are the chief products. Rich natural resources, including coal, oil, natural gas, limestone, fire clay, and lumber, help to support an extensive and varied industry. The production of steel, glass, distillery products, chemicals, rubber, paper, automobiles, and electrical machinery is significant on a national scale.

All these diverse watershed activities and a population of about 20 million (1970) represent a spectrum of extensive and often critical demands on water resource needs and uses. One of the most important of these demands is the requirement for reservoir discharge for low-flow augmentation to maintain the in-stream assimilation of thousands of tons of domestic, industrial, mining, and other types of wastes. Even if tertiary waste treatment becomes universal, this requirement will continue to be a perpetual water management problem in this basin.

The need for flow augmentation is partially met by the routine operation of the reservoir system in meeting flood control and navigation objectives. Regulated release of summer storm runoff and of storage specifically provided for low-flow augmentation can at times constitute as much as two thirds of the total flow in parts of the main stem. The reduction of reservoir pool levels in late summer and early fall also offsets the most critical low-flow problems. In addition, special storage for specific water quality problems is provided in some reservoirs.

The problem of protecting the quality of reservoir storage and discharge has become increasingly critical. Rapid commercial development and increasing population have generated an intense dependence on reservoir storage as well as a degradation of reservoir inflows. Although progress is being made toward pollution control at the source, this will resolve only part of the overall problem.

Typically, the reservoirs in this basin are thermally stratified. Usually, there is sufficient organic loading to result in oxygen depletion below the thermocline. Sedimentation has not been a significant problem to date, but it might be for a few proposed reservoirs. There are several other factors or conditions that are common in many of the reservoirs; e.g., in the coal regions, sulfuric acid, sulfates, iron, and manganese tend to be universal problems.

In spite of many similarities, each of the 56 existing reservoirs tends to be unique in one or more water quality factors. These differences may constitute significant problems in understanding the cause and effect relationships of chemical and biological reactions as well as the operation of reservoirs. Relationships involving the size and shape of the impoundment, the watershed area, and the topographic, geologic, hydrologic, and land use characteristics are obvious and predictable. For example, the storage in a small reservoir is extremely vulnerable to acid mine wastes unless it is highly buffered. Elsewhere, the factors are too subtle, or so many variables are involved that measurement, correlation, and prediction are difficult. For example, reservoir inflow will seek a level of identical density, which could be above, within, or below the thermocline. The reactions that occur then may vary drastically depending on the presence or absence of oxygen, the water temperature, the materials in solution or suspension, and the kinds and numbers of organisms present.

The initial reservoirs in this basin were provided with only bottom discharge. Biologists eventually pointed out that a radical change to the downstream aquatic environment was being brought about by discharges of cold water into a previously warmwater stream. Other detrimental effects were also brought to light. As a result, attempts were made to achieve greater flexibility for reservoir discharge control. A series of structures were built with low-flow bypass arrangements permitting discharge from various pool elevations. The Corps of Engineers has been extensively involved in evaluating and in seeking to improve this capability.

Preimpoundment water quality surveys are now essential to provide design criteria for selective withdrawal structures and guidelines for reservoir regulation in terms of water quality requirements. Heat budget analysis and prediction of temperature characteristics provide the basis for the design criteria and for the evaluation of the relationship of storage to tail water temperature objectives. It is believed that correlations and predictions of other parameters can be refined and integrated in the design and operating approaches.

Although thermal stratification has been studied in the oceans and in natural freshwater lakes for many years, only recently has attention been given to man-made reservoirs with the thought of controlling the quality of stored and released water. It was observed that thermal gradients in impoundments differed noticeably from those in natural lakes. In fact, impoundments having similar volumes and surface areas and located in close proximity to each other differ significantly.

Although the sources of energy and the mechanisms responsible for thermal stratification are the same in both instances, the difference lies in the effect of net advection in terms of energy and mass. The ratio of inflow and outflow volume to storage varies over a wide range for man-made reservoirs, whereas it is generally an insignificant factor in natural lakes. Water entering a stratified impoundment or lake can spread over the surface or occupy a discrete layer at a level of neutral buoyancy according to its temperature-density relationship. Outflow from a natural lake occurs at the surface, whereas the outlet structure of a man-made reservoir may allow withdrawal from any level. Low-level discharge results in the downward displacement of the warm upper layers, which causes a more gradual thermal gradient than that found in the classic lake profile.

Because of the temperature-density relationship a well-defined thermal gradient serves as a highly flexible diaphragm separating the epilimnion from the hypolimnion. Although the corresponding density gradient is small in magnitude, it is sufficient to form a barrier to the vertical transfer of thermal energy.

In addition to being an energy barrier the density gradient effectively isolates the hypolimnion storage from the surface reaeration process. If there is even a moderate amount of organic matter suspended in the lower levels, oxygen depletion is swift once the transfer of dissolved oxygen is blocked. As the dissolved oxygen concentration nears total depletion, facultative and anaerobic microorganisms proliferate in and above the mud-water interface. Some use mineral oxides, sulfates, and more complex inorganic compounds as a source of energy, whereas others decompose organic matter. The mineral compounds are thus reduced to their more soluble state, whereas the waste products of the decomposition process include carbon dioxide, hydrogen sulfide, and methane. Part of the dissolved carbon dioxide dissociates to form a weak acid. This dissociation lowers the *p*H, a more favorable environment for the solution of the reduced forms of iron, manganese, and sulfur compounds thus being created.

To achieve optimal control of such factors, two areas of activity are being expanded to improve the design and operation of selective withdrawal structures. Laboratory investigations of density currents have been conducted to develop techniques for analyzing the features of the withdrawal zone. Mathematical models are also being used to simulate the thermal characteristics of impoundments.

Density currents, long familiar to oceanographers, are being studied with hydraulic models. These studies are yielding information pertaining to the vertical dimensions of the withdrawal zone, the velocity distribution within the zone, and the relationship of the shape and location of the intake port to these factors. Prototype verification has been difficult because of the small velocities involved. However, by integrating the computed velocity profile and prorating density according to the discharge distribution, one can determine the density of the outflowing water. These values are in very close agreement with observed release temperatures.

The basinwide environmental impact of a reservoir system is not the only aspect of water management that is difficult to depict. There is a tendency to oversimplify grossly day-to-day operating problems, hydrologic procedures, and the involved decision-making process.

The extent of meteorological variance and the limited reliability of rainfall and runoff predictions necessitate careful daily analysis. Summer storms may produce intense rainfall over one or a series of reservoir watersheds. Rainfall generated by hurricanes and tropical storms is an additional and most imposing threat in the basin. Drought provides another set of complications in terms of evaluating current conditions and the consequences of judgment decisions.

An equally demanding aspect is the consideration of priorities and alternatives involving the various requirements and uses of reservoir storage. It is impossible to avoid incompatibility between water use interests, and the conflict is usually intensified during hydrologic extremes. These conflicts may involve strictly local versus regional interests, such as desires for stable pool levels versus downstream needs for discharge. On the other hand, national interests may be involved if the problem involves a power shortage or consequential flood damages. In spite of all the available logic based on safety factors, economic guidelines, and the hard facts of hydrologic reality, resolution may be difficult.