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DEVELOPMENT OF WATER RELEASE PLANS FOR MINIMIZING FISH KILLS BELOW TULSA DISTRICT, CORPS OF ENGINEERS IMPOUNDMENTS

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ABSTRACT

Late summer fish kills comprised primarily of striped bass (*Morone saxatilis*) and associated with high water temperatures, low levels of dissolved oxygen (DO) and fish entrapment occasionally occur in the tailwaters of Tulsa District, Corps of Engineers impoundments. In response to these kills, studies were initiated to develop means of using minimal water releases to consistently maintain adequate temperature and dissolved oxygen conditions for fish survival below these projects. Activities included the use of the computer model, SELECT, for the prediction of minimum required releases, followed by field verification of predicted release characteristics. Results of studies at two lakes are presented here. At Eufaula Lake, Oklahoma, release plans were developed for preventing tailwaters anoxia resulting from leakage of low DO waters through power penstocks. At Ft. Gibson Lake, Oklahoma, releases were used to prevent fish mortality caused by elevated water temperatures. In both instances, the SELECT model adequately predicted release characteristics and low level (approximately 0.7 m^3/sec), continuous sluice releases were successfully used to prevent fish kills.

Fish kills occasionally occur below Tulsa District (TD) Corps of Engineers dams. These kills generally occur during late summer and are associated with low and infrequent water releases, high water temperatures, and low dissolved oxygen (DO) concentrations in project tailwaters. The most recent major fish kill

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occurred on August 16, 1987 when approximately 1000 striped bass (*Morone saxatilis*), ranging in size from 3 to 15 kg, died in the stilling basin at Ft. Gibson Lake, Oklahoma. This kill, along with others historically experienced at other Corps projects, prompted the TD to research methods of minimizing fish mortality below operational projects during critical summer months.

While the exact combination of factors leading to tailwaters fish kills are not known, major contributing factors are believed to be fish entrapment, high water temperatures, and low DO. Members of many fish species (most notably striped bass) frequently move upstream and congregate below dams during water releases. When releases cease and water levels subside, large numbers of fish can become trapped in project stilling basins or otherwise precluded from downstream escape. During late summer, when water releases are minimal and infrequent, tailwaters temperatures rise and dissolved oxygen can become depleted. Oxygen problems are further aggravated by low DO releases during late summer generation periods at TD projects which provide hydropower. If allowed to persist, these conditions can lead to fish stress and eventual mortality.

The main objective in formulating release plans for preventing fish kills below TD dams was to develop a means of consistently maintaining adequate DO and temperature conditions for fish survival below these projects with minimum water releases. Water levels are generally critical during late summer and releases can result in lost income and power potential at hydropower projects. The problem is further compounded by the wide variety of designs, structural characteristics, operational regimes, and water quality at TD impoundments. These differences dictated the need for development of release plans specific to each individual project.

STUDY AREAS

Eufaula and Ft. Gibson Lakes, built and operated by the TD Corps of Engineers, are located in eastern Oklahoma. Characteristics of these impoundments are presented in Table 1. Authorized project purposes for Ft. Gibson Lake are flood control and hydroelectric power while those for Eufaula Lake include flood control, hydroelectric power, water supply, and navigation. Viable tailwaters populations of striped bass provide a popular fishery below both impoundments.

METHODS

The first step in release plan development was the definition of conditions critical to fish survival. While precise predictions of these conditions are difficult due to a number of physical, chemical, and biological interactions, general conditions which result in fish stress and mortality are fairly well-known.

Table 1. Characteristics of Lakes Eufaula and Fort Gibson, Oklahoma

	Eufaula Lake	*Fort Gibson Lake*
Location	River Mile 27.0 Canadian River	River Mile 7.7 Grand (Neosho) River
Year completed	1964	1949
Surface elevation (m)[a]	178.3	168.9
Surface area (ha)[a]	42,713	8,057
Depth at dam (m)[a]	28	15
Capacity (ha-m)[a]	285,533	45,052
Length of dam (m)	975	911
Tainter gates		
Number	11	30
Dimensions (m)	12.2 X 9.8	12.2 X 10.7
Spillway crest elevation (m)	172.2	166.7
Sluices		
Number	1	10
Dimensions (m)	1.7 X 2.1	1.7 X 2.1
Invert elevation (m)	152.4	153.0
Penstocks		
Number	3	4
Diameter (m)	6.7	5.5
Invert elevation (m)	154.2	155.9

[a] At top of power pool.

Guidelines listed below were used as indicators of critical conditions in TD project tailwaters.

Guidelines

(1) Fish entrapment – Conditions which resulted in fish trapped in stilling basins, larger tailwater pools, or otherwise precluded from downstream escape where conditions might be more favorable for survival. Development of this condition, combined with measurements described in *either* numbers (2) or (3) below was considered cause for immediate corrective action.

(2) Dissolved oxygen – MAXIMUM (vertical and horizontal) mid-morning DO concentration of 3.0 mg/l. Readings were taken at 1 m depth intervals (vertical) at several representative locations in the tailwaters pool (horizontal).

(3) Water temperature – MINIMUM (vertical and horizontal) mid-afternoon water temperature of 26°C in project tailwaters possessing populations of striped bass. Water strata with temperature necessary for maintaining adult striped bass (<26°C) must also possess adequate (>3.0 mg/l) DO concentrations [1, 2].

(4) Visible signs of fish stress – Large numbers of fish gulping air at the water surface, erratic swimming patterns, or other unusual visible fish behavior. These observations may indicate fish stress due to factors other than temperature and DO (i.e., toxicants) and were always considered cause for immediate corrective action regardless of other conditions.

While the interpretation of critical tailwater conditions required the use of common sense at specific projects, the above descriptions were used as general guidelines. Development of these conditions did not necessarily guarantee that a fish kill would occur, but did represent a situation where the potential for a kill was high if immediate corrective measures were not taken. It became apparent that tailwater monitoring is labor-intensive and interpretation of data difficult. For this reason, release plans were developed with the objective of minimizing or eliminating the need for data collection and interpretation by TD project personnel.

The next step in release plan development involved the choice of outlet type. Water releases can be accomplished via several types of outlets at many TD dams. These outlet types generally include tainter gates, sluices, and hydropower penstocks. However, a great deal of structural variation exists among TD projects, and many impoundments do not possess all outlet types. Late summer temperature and DO release characteristics for each outlet type are summarized below.

Penstocks – Hydropower releases are generally of large magnitude and are characterized by low water temperatures and low DO. Late summer DO levels are frequently low due to withdrawal from anoxic water strata and low levels of aeration in turbines.

Tainter gates – Near-surface waters are generally released through tainter gates. Releases are therefore characterized by high water temperatures and high DO concentrations.

Sluices – While releases via sluices usually involve withdrawal from anoxic water strata, aeration (often approaching saturation) generally occurs with this type of release. Low-level sluice releases are therefore characterized by low water temperatures and high oxygen concentrations and are particularly useful in maintaining tailwaters conditions necessary for fish survival. Even when water temperatures are not critical, sluice releases are still desirable due to the increased oxygen-holding capacity of cold water.

Following selection of release outlets and discharge rates, the timing of releases was determined. This generally involved selection of one of three possible regimes: as-needed releases, periodic releases, and continuous releases. These alternatives and their inherent advantages and disadvantages are discussed below.

As-needed releases – As-needed releases are made only when tailwaters conditions reach levels critical to fish survival. The primary advantage to this regime is that it provides current information on tailwater conditions and is water-conservative. The major disadvantage is the need for constant water quality monitoring by project personnel. Other disadvantages include the danger of missing critical periods and the possibility of misinterpretation of critical conditions.

Periodic releases – Periodic releases are made at regular, predetermined intervals. Time intervals are generally determined through test releases and post-release monitoring. Advantages to this regime include an intermediate degree of water conservation without the requirement for intensive monitoring. This scheme, however, involves significant disadvantages. Determination of release intervals is based on conditions at the time of test releases. Environmental conditions vary significantly over time and predetermined intervals will likely not apply throughout a summer. Establishment of these intervals also does not incorporate necessary adjustments for unusual or abnormal weather conditions (extreme heat, prolonged cloudiness, etc.). In addition, the selection of release intervals is complicated by varying generation schedules at hydropower projects. A final disadvantage involves the increased labor demand required for gate changes at the project.

Continuous releases – Continuous releases involve low discharge releases that are maintained throughout critical summer months. The major disadvantage to this scheme is the requirement for slightly more water than is necessary for the other two regimes. Advantages to these releases, however, are many. A major advantage is the elimination of labor requirements for intensive water quality monitoring and gate changes by project personnel. Continuous releases also eliminate the uncertainty associated with periodic or as-needed releases. Because conditions are not allowed to deteriorate to critical levels, this regime provides a certain degree of buffering during periods of unusual or abnormal weather. These releases also provide a localized "safe" zone for fish during low DO power generation. A final advantage to continuous releases is that they ensure the release of cool, oxygenated water during week-ends and nighttime hours—periods which have historically been most critical to fish survival.

Following selection of outlet type and release regime, minimum required discharge rates were predicted. The computer model, SELECT, developed by the Corps of Engineers Waterways Experiment Station (WES) proved valuable in these investigations. This one-dimensional model predicts withdrawal and release characteristics based on reservoir density and quality profiles, outlet configurations, and discharge [3]. Model predictions are, however, limited to discharge characteristics only and do not include downstream projections.

While SELECT is capable of computing release quality for user-specified parameters treated as conservative substances, parameters of primary interest to this study were temperature and DO. The subroutine AERATE accounts for the reaeration of release waters passing through gated conduit outlet works and is based on the "energy dissipation model" (EDM) developed by Tsivoglou and Wallace [4] and reviewed by Wilhelms and Smith [5]. Use of the SELECT model by the Nashville District Corps of Engineers yielded temperature predictions typically within 0.3°C of observed values and DO predictions within 0.5 mg/l [6]. Wilhelms and Smith [5] reported SELECT-predicted versus observed standard deviations of 2.0°C for temperature and 0.7 mg/l for DO.

Required input data for SELECT include lake surface elevation, bottom elevation at dam, outlet types, elevations, dimensions, and withdrawal angles, release flows, and in-lake temperature and density profiles. If release characteristics for quality parameters are desired, profiles for these parameters must also be supplied.

RESULTS AND DISCUSSION

Eufaula Lake, Oklahoma

The greatest potential for fish kills below Eufaula Dam exists during summer months when water releases are minimal and infrequent. Intervals of several days frequently separate generation periods during summer months. Zero flow conditions result in the formation of a large, isolated tailwater pool which extends from the dam to a downstream buoy line. Depth of the pool varies from approximately 12 m at the dam to several cm at the downstream end. Tailwaters immediately below the spillway are separated from those in the power bay by a long wingwall which generally reduces mixing of these waters. Dimensions of the spillway pool are approximately 159 by 183 m with an estimated volume of 1.75×10^5 m^3.

Despite the large volume of the tailwaters pool, DO depletion occurs rapidly during summer months. Oxygen problems are further aggravated by the release of low DO water during summertime power generation. If allowed to deteriorate to critical levels, oxygen depletion in this pool can result in fish mortality. Water temperatures do not appear to be critical due to the large volume of the pool, the release of cold water during hydropower generation, and the leakage of cold water through power penstocks. A large fish kill occurred in the Eufaula tailwaters in the summer of 1974. Since that time, smaller-scale kills have occasionally been observed.

Initially, a summertime periodic release scheme was proposed for Eufaula Lake. In an attempt to define required release intervals, a sluice release (3.5 m^3/sec) was used to elevate tailwaters DO and post-release conditions monitored for DO reduction. This release was also conducted to test the predictive capabilities of the SELECT model. The release was initiated at 1300 h CST on June 13 1988 and was maintained for three hours and twenty minutes. Measurements of water temperature, DO, pH, and conductivity were recorded at five locations in the tailwaters pool prior to the release, at regular intervals

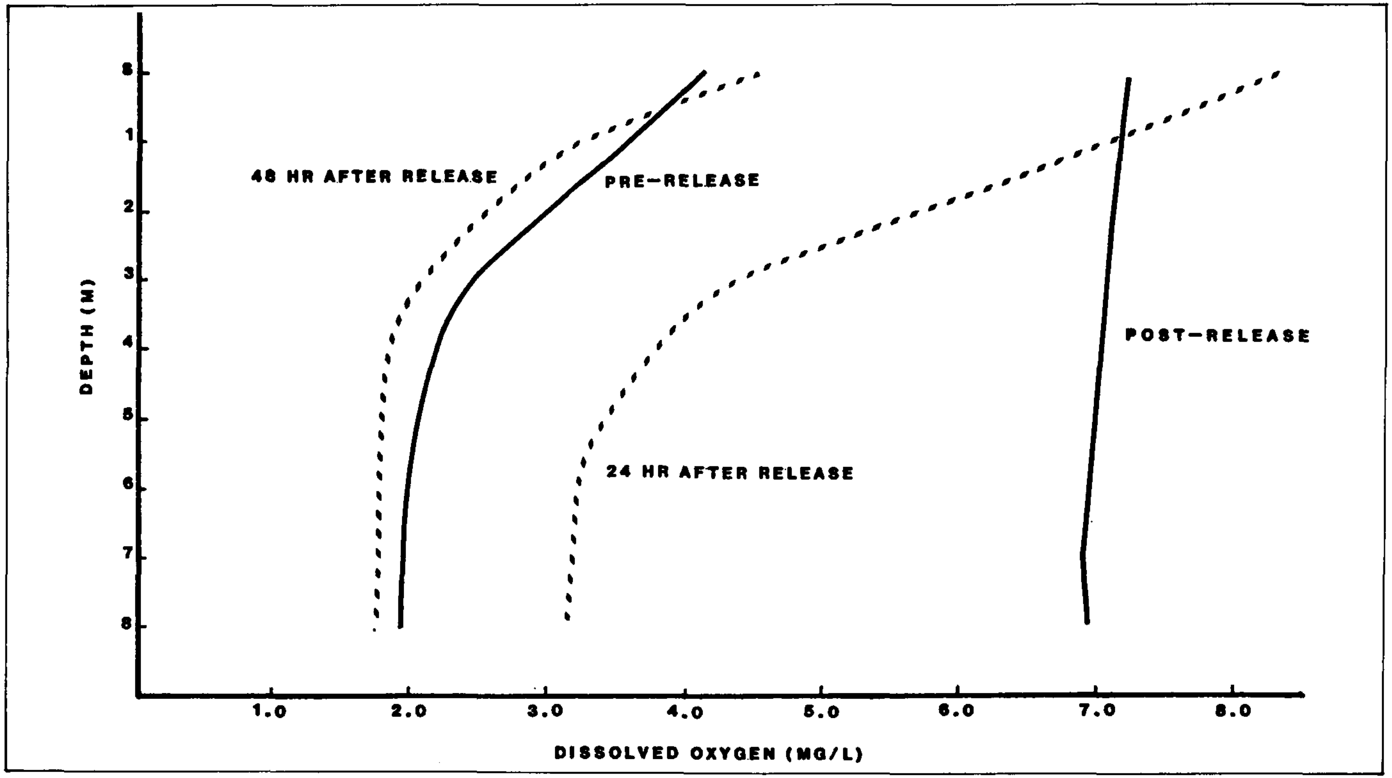

Figure 1. Effects of June 13, 1988 test sluice release (3.5 m^3/sec for 3 hr 20 minutes), Eufaula Lake, Oklahoma tailwaters. Measurements taken from right wing wall.

during the release, and immediately following sluice gate closure. Measurements of these parameters continued for forty-eight hours (Figure 1). No power generation occurred during this time.

Prior to the release, DO concentrations in the Eufaula tailwater pool were approaching levels considered critical to fish survival. Concentrations were around 4 mg/l at the surface and declined to less than 2 mg/l near the bottom of the water column. Water temperatures were low (16 to 18°C). As a result of the release, DO concentrations were elevated to approximately 7 mg/l throughout the stilling basin water column and were as high as 10.5 mg/l near the downstream buoy line. Increases in DO were not as dramatic in the power bay where post-release concentrations ranged from 3.5 to 5.9 mg/l at the bottom and surface respectively. Water temperatures decreased slightly (approximately 1°C) following the release and were constant throughout the water column. Dissolved oxygen concentrations declined considerably twenty-four hours after the release and returned to pre-release conditions in forty-eight hours (Figure 1).

Due to the violent nature of the release and the physical distance to the sluice, it was not possible to position the monitoring probe directly in the release water. Therefore, precise measurements of temperature and DO in the release stream were not possible. However, it was apparent that the SELECT model did a reasonably good job of predicting release parameters. Predicted values for temperature and DO were 15.7°C and 9.6 mg/l respectively. Observed values (measured adjacent to the release stream) were 16.8°C and 7.7 mg/l. Agreement between predicted and observed values would probably have been closer if the probe could have been placed directly in the release stream and measurements conducted prior to mixing of pool and release waters.

This test release also verified the effectiveness of sluice releases in aerating waters withdrawn from low DO hypolimnia. Reaeration through gated conduits has reportedly been sufficient to raise downstream DO to approximately 80-100 percent saturation regardless of flow and initial DO content [5]. At the time of the test release, lakewater temperature and DO concentrations at the sluice intake elevation were 15.5°C and 2.5 mg/l (25% saturation) respectively (Figure 2). The withdrawal zone, as calculated by SELECT, extended approximately 11 m above the lake bottom at Eufaula Dam. SELECT-predicted oxygen saturation in the release was 96 percent while that measured in the tailwaters pool adjacent to the release was approximately 80 percent. Throughout the entire tailwaters, mean oxygen concentrations were raised from 28 percent saturation prior to the release to 74 percent saturation immediately following sluice gate closure.

Due to rapid oxygen reduction in the Eufaula Lake tailwaters following a release and the subsequent need for frequent releases and gate changes, the periodic release regime was abandoned. Investigations were also conducted to determine the cause of tailwaters DO depletion. Biochemical oxygen demand (BOD_5) analyses yielded low values (2-3 mg/l) and oxygen reductions were

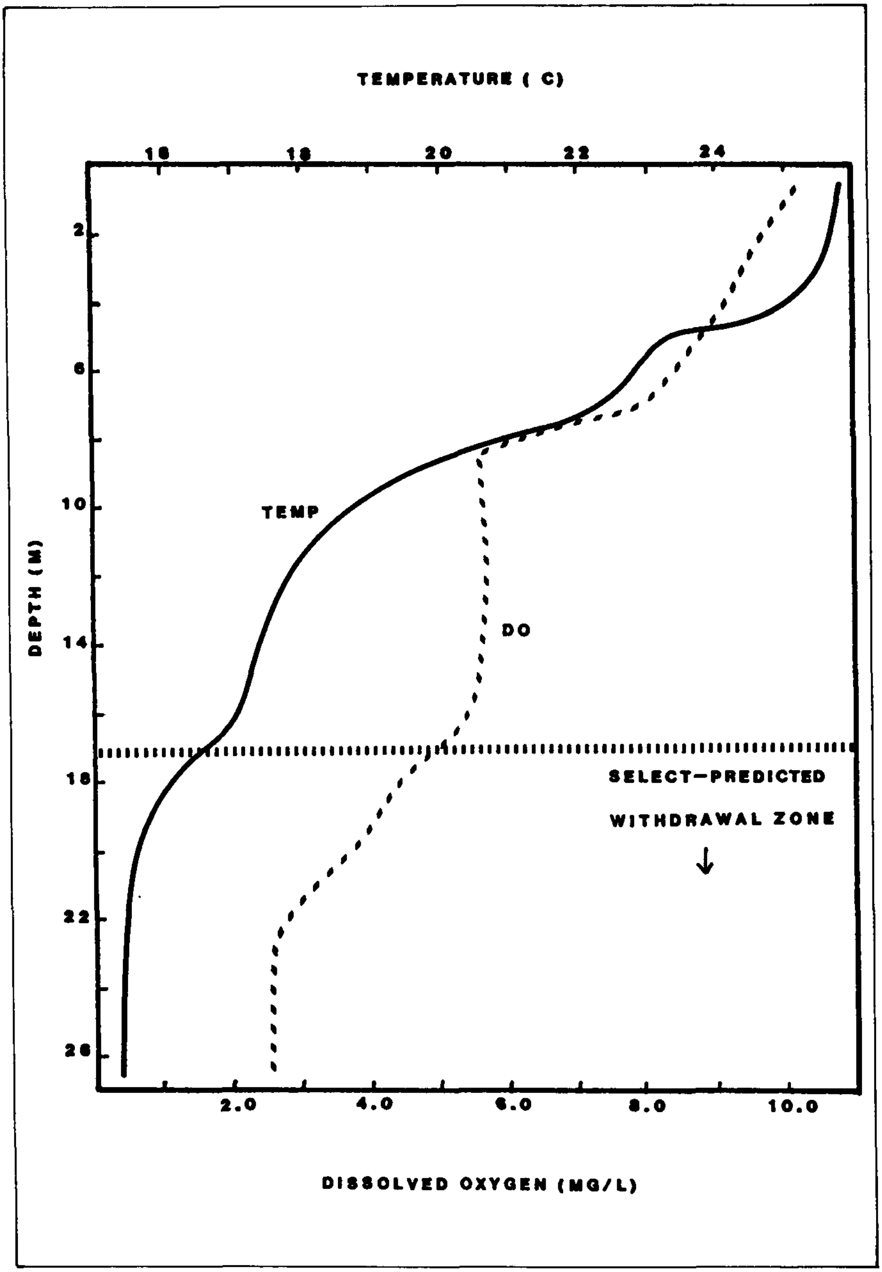

Figure 2. Vertical profile of temperature and dissolved oxygen on June 8, 1988, immediately above Eufaula Dam.

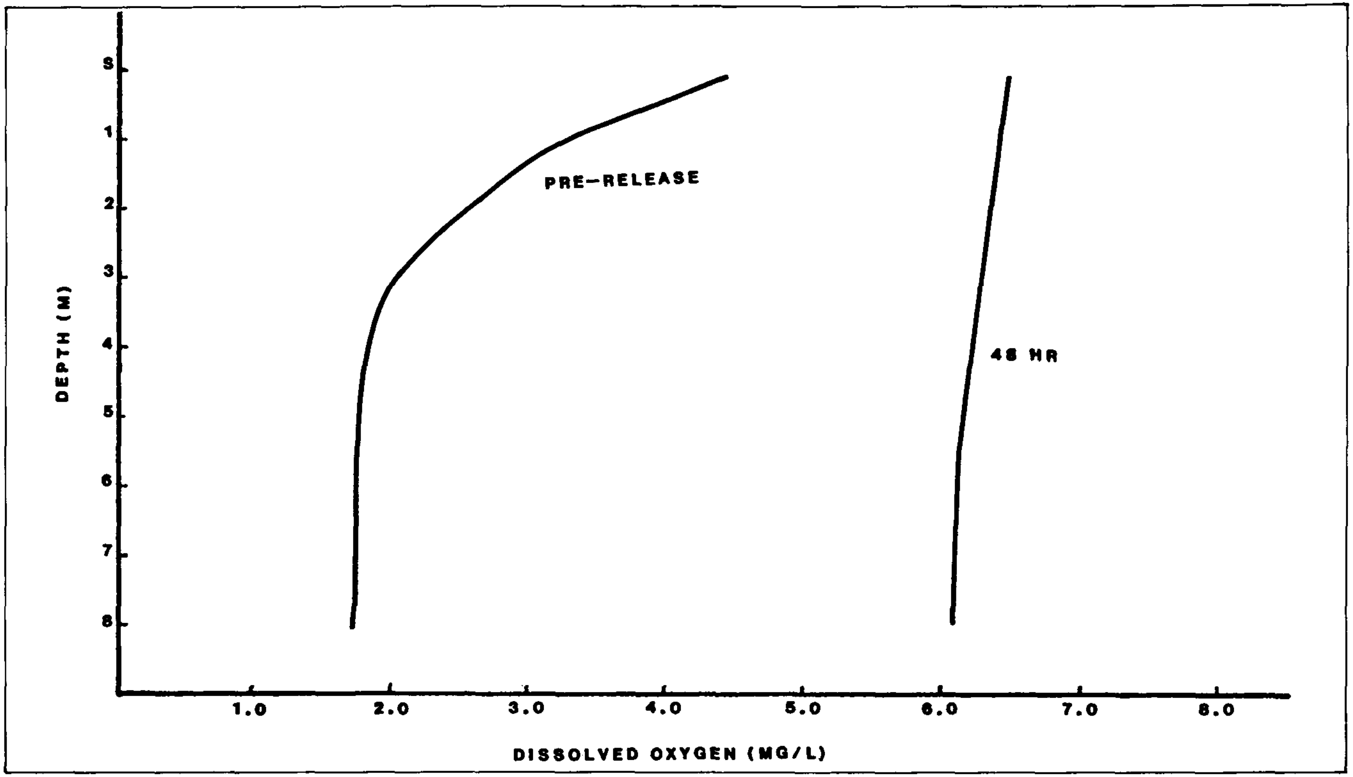

Figure 3. Effects of 0.7 m^3/sec continuous sluice release, Eufaula Lake, Oklahoma tailwaters. Measurements taken from right wing wall.

attributed to low-level leakage of oxygen-deficient lakewaters through power penstocks. Consistently low DO readings immediately below penstock outlets (even during tailwaters aeration periods) and reports of similar occurrences at other Corps and Tennessee Valley Authority (TVA) impoundments [7-9] served as the basis for this conclusion. Using the estimated pool volume and the approximate forty-eight hour tailwaters turnover time, total penstock leakage was estimated to be 1 m^3/sec. Similar leakages of 0.5 to 1.8 m^3/sec have been reported at TVA dams [8].

On June 29, 1988, a continuous sluice release of approximately 0.7 m^3/sec was initiated at Eufaula Dam. This discharge rate corresponded to the smallest measurable sluice gate opening (approximately 2.5 cm) and approximately matched the estimated leakage through the penstocks. SELECT-predicted characteristics for temperature and DO at this discharge were 15.6°C and 9.6 mg/l respectively. Measurements of temperature and DO were recorded throughout the tailwaters approximately forty-eight hours after initiation of this release (Figure 3). Tailwaters were generally well-mixed, low in water temperature, and possessed high concentrations of dissolved oxygen throughout the water column. Oxygen concentrations remained low only in deep water strata in the power bay. The continuous release was maintained through the end of September, 1988 with no reported fish mortalities.

Future plans call for initiation of the continuous, 0.7 m^3/sec release at Eufaula Dam on June 1 of each year. The release will be maintained until the end of September or until lake destratification is apparent. Water requirements for this regime are 917.6 ha-m. This corresponds to an approximate 3 cm drop in lake surface elevation over the entire summer and is insignificant in comparison to evaporative losses (30 to 45 cm) over the same period.

Ft. Gibson Lake, Oklahoma

The highest potential for fish kills below Ft. Gibson Dam occurs as a result of fish entrapment in four small bays formed between the spillway and stilling basin end sill. During flood releases, individuals of many fish species (most notably striped bass) move upstream to Ft. Gibson Dam. When releases cease, the tailwater elevation subsides to a level below that of the end sill crest, forming four narrow, shallow basins immediately below the dam. These bays are physically isolated from one another and from the rest of the tailwaters. Characteristics of these bays are presented in Table 2. Large numbers of fish are frequently trapped in these bays and late summer fish kills can occur due to high water temperatures, low DO, or a combination of both factors. Unfortunately, large, adult striped bass are most sensitive to elevated water temperatures and are generally the first to die. Approximately 1,000 striped bass, ranging in size from 3 to 15 kg, died in these bays on August 16, 1987.

Table 2. Characteristics of Stilling Basin Bays, Fort Gibson Lake, Oklahoma

	Bays[a]			
	1	*2*	*3*	*4*
Length (m)	207	92	92	78
Width (m)	16	21	21	16
Depth (m)	1.5	1.5	1.5	1.5
Surface area (m^2)	3,312	1,932	1,932	1,248
Volume (m^3)	4,968	2,900	2,900	1,872
Outlet works above bays (number)	tainters (13)	tainters (6) sluices (5)	tainters (6) sluices (5)	tainters (5)

[a] Bays numbered west to east.

The problem at Ft. Gibson is further compounded by the small water volume of the basins and the inability to release cool water through sluices to the two outside bays. Sluices are located above the middle two bays (Bays 2 and 3) but releases to the far west and east basins (Bays 1 and 4 respectively) must be made via tainter gates. In late summer, water from tainter gate releases is high in dissolved oxygen but unfortunately also possesses high water temperatures. The bays face south, are small and extremely shallow, and are therefore susceptible to intense heating and rapid fluctuations in water temperatures.

Various alternatives for maintaining adequate temperature and DO in the Ft. Gibson stilling basin bays were evaluated. Regimes involving as-needed or periodic releases were avoided due to the extreme difficulty of water quality monitoring in the bays and the anticipated requirement for frequent, labor-intensive, and, in effect, nearly continuous releases due to small basin volumes.

Fish removal from the basins was also considered. Due to the small size of the bays, it would have been possible to remove all fish from the bays and release them downstream. Fish could have been removed at the beginning of summer, thus eliminating concern about fish mortality. However, during power generation, water levels occasionally rise slightly above the end sill (particularly at the two east bays). This would have allowed fish to possibly reenter the bays, would have resulted in uncertainty about the number of fish in the bays, and might have necessitated frequent fish removal.

The most feasible regime for minimizing fish mortality in the bays involved low-level, continuous releases to each basin. Water was discharged via one sluice in each of Bays 2 and 3 and via one tainter gate in each of Bays 1 and 4. Following prediction of release characteristics by the SELECT model, discharge rates corresponding to minimum measurable gate openings (approximately 2.5 cm for both sluices and tainter gates) were selected. Water conservation and compression of the lake withdrawal zone resulting in the release of cooler water formed the basis for this selection. Release rates were 0.6 and 0.9 m^3/sec for sluice and tainter discharges respectively. These rates resulted in approximate water turnover times of 1.4 hours for Bays 2 and 3, 1.5 hours for Bay 1, and 0.6 hours for Bay 4. Despite the release of warm, near-surface waters via tainter gate releases in Bays 1 and 4, it was anticipated that continuous turnover of waters would reduce excessive heating in these basins.

Temperature and DO conditions in the bays below Ft. Gibson Dam were not allowed to deteriorate to critical conditions during the summer of 1988 for fear of additional fish kills. Therefore, late summer values for these parameters in the absence of water releases are unknown. In addition, precautionary continuous tainter gate releases of approximately 1 m^3/sec were supplied to all bays prior to test release evaluations.

A test release of 0.6 m^3/sec through the middle sluice above Bay 2 was conducted on the morning of June 21, 1988. Measurements of water temperature and DO were conducted throughout the release. Water temperatures were reduced approximately 1.6°C in two hours by the release. The magnitude of this change would be expected to be much greater later in the day and toward late summer when initial basin water temperature would be much higher. In comparison, water temperature in Bay 1 exceeded that in Bay 2 by approximately 4°C following the release. After two hours, water temperature in Bay 1 was 21.5°C and DO 8.6 mg/l. SELECT-predicted values were 20.2°C and 8.4 mg/l. The continuous release regime described above was maintained throughout the end of September 1988 with no reported fish mortalities.

Future plans call for implementation of the continuous, low-level release to all bays below Ft. Gibson Dam from May 1 to September 30 of each year. It was also recommended that when flood discharges cease, tainter gates above the middle two bays be closed last. This will hopefully attract most fish to the middle bays where late summer water temperatures can be more easily controlled by sluice releases.

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