OXYGEN DEPLETED WATERS: ORIGIN AND DISTRIBUTION IN LAKE POWELL, UTAH - ARIZONA

by

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INTRODUCTION

The fishery of Lake Powell is strongly affected by the transient distribution of oxygen depleted waters during the course of an annual cycle. The principal problems are (1) the existence of a shallow oxygen minimum layer, frequently anerobic, during summer stratification, and (2) oxygen-deficient water at depth during the winter. In this paper we will describe and explain the origin and distribution of these oxygen poor waters.

Physiographic setting. Figure 1 locates Lake Powell in the heart of the Colorado Plateau and shows its plan view configuration which is basically that of a drowned river system. The lake is situated on a high, arid plateau devoid of any natural lakes. It occupies a deeply dissected channel of the Colorado River, the former Glen Canyon sector of the river. The floor of the reservoir is the incised bed of the former river, 150-240 m in width at its bottom, with a nearly uniform grade of 0.038%. Vertical walls, in some cases overhanging, rise hundreds of meters above much of the lake surface. The canyon-type morphology is reflected in the hypsographic curve of the lake, which is strongly convex upward (Johnson and Merritt, 1979). The thalweg area of the lake is dominated by a steep-sided, deep-water shore; shoaling water is generally found at the heads of side-canyon tributaries which are oriented normal to the thalweg (Figure 1). It is noteworthy that the side-canyons are generally dry canyons without major or perennial streams draining into them. Historically, some 95% of the discharge through the Glen Canyon reach of Colorado River has been in transit from upstream, leaving only 5% to be drained from local watersheds.

Circulation. With respect to convective circulation Lake Powell mixes only once a year during the winter cooling period generally from early October through early March when thermal stratification begins to assert itself.

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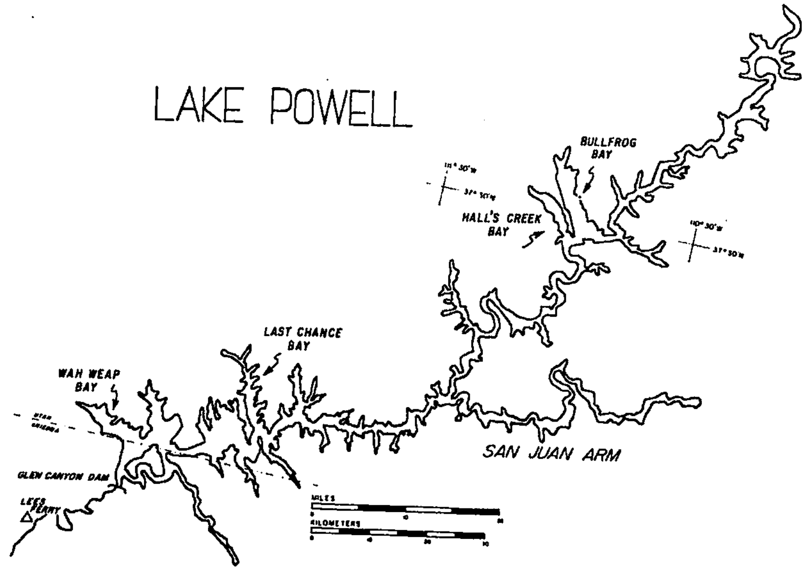

Figure 1.
Plan view of Lake Powell at full lake volume.

The summer epilimnion extends 10-20 m (30-60 ft) below the surface depending on season and location. During the course of a typical year Lake Powell receives two distinctive types of inflow; a lower density water associated with the spring flood, and a higher density water during the winter. The influx of warm, fresh water into Lake Powell during the spring flood describes a distinctive overflow density current while the intrusion of cold, salty water during the winter assumes the form of an underflow density current extending the full length of the lake (Johnson and Merritt, 1979). In addition, the extraction of water from the dam penstocks creates a pervasive and strong withdrawal current at mid-depth within the lake. The surface convective mixing zone is confined to the waters above the withdrawal current zone, i.e. convective mixing is effectively blocked by the withdrawal current and does not penetrate to the bottom of the lake (Johnson and Merritt, 1979).

Methods. Sampling and analytic techniques used in this study are specified by Johnson and Merritt (1979). All oxygen determinations were done by the Winkler method on water samples collected by Van Dorn bottle.

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DISTRIBUTION OF DISSOLVED OXYGEN

In late summer a distinctive oxygen minimum layer develops in the metalimnion of Lake Powell immediately below the epilimnion, forming a negative heterograde profile (Aberg and Rhode, 1942). This phenomenon appears to be comparable to that observed in Lake Mead (Hoffman and Jonez, 1973). The oxygen depletion zone develops every summer below the mixed layer with its core 45-60 feet below the surface. This oxygen minimum layer occurs annually and extends the full 175-mile length of Lake Powell (Figure 2, column A). Its upper boundary is a sharp, discrete surface corresponding to the epilimnion-metalimnion boundary. The lower limit of the summer oxygen minimum layer is more diffused, but usually reaches about the 200-foot level. Although the oxygen minimum layer is well developed in the thalweg area of Lake Powell, where the water is deep, it is better developed in the side canyons, which form shoaling water embayments distal to the thalweg (Figure 1). The summer oxygen depletion zone intensifies away from the thalweg toward the heads of these side canyons, where anerobic waters may occur. The core of the oxygen minimum layer (45-60 feet) is thus characterized by a horizontal gradient with anerobic water at the sides of the lake grading laterally to 2-4 mg/l dissolved oxygen at the mouths of the bays in the mainstem of the lake (Figure 3). We show in Figure 3 that this pattern recurs year-after-year within a given bay and bay-after-bay in a given year. We show in Figure 4 how this phenomenon developed in Last Chance Bay (Figure 1) during one summer.

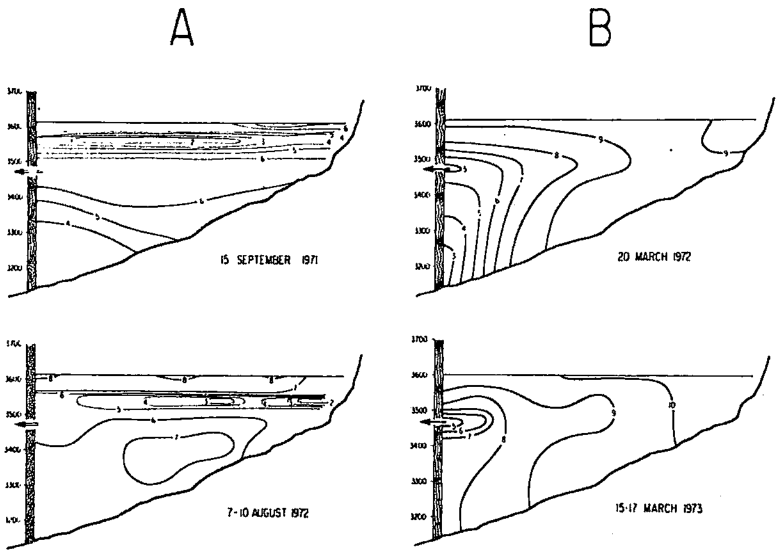

Figure 2.
Distribution of dissolved oxygen along the main-stem of Lake Powell. Column A shows two examples of a fully developed oxygen minimum layer extending the entire 175-mile length of the lake. Column B shows two cases where old bottom water is in the process of being purged and replaced by an underflow density current from upstream.

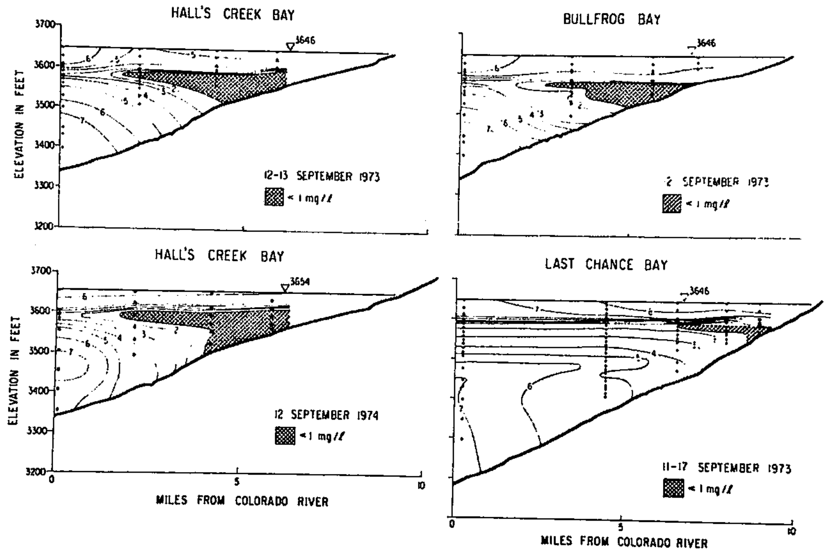

Figure 3.
Distribution of dissolved oxygen in several bays on Lake Powell (see Figure 1 for location). The black dots represent sample collection points. Note that the oxygen concentration at any depth diminishes towards the bay head. Also note that the configuration of the oxygen deficit changes from negative heterograde at the bay mouth to clinograde at the bay head.

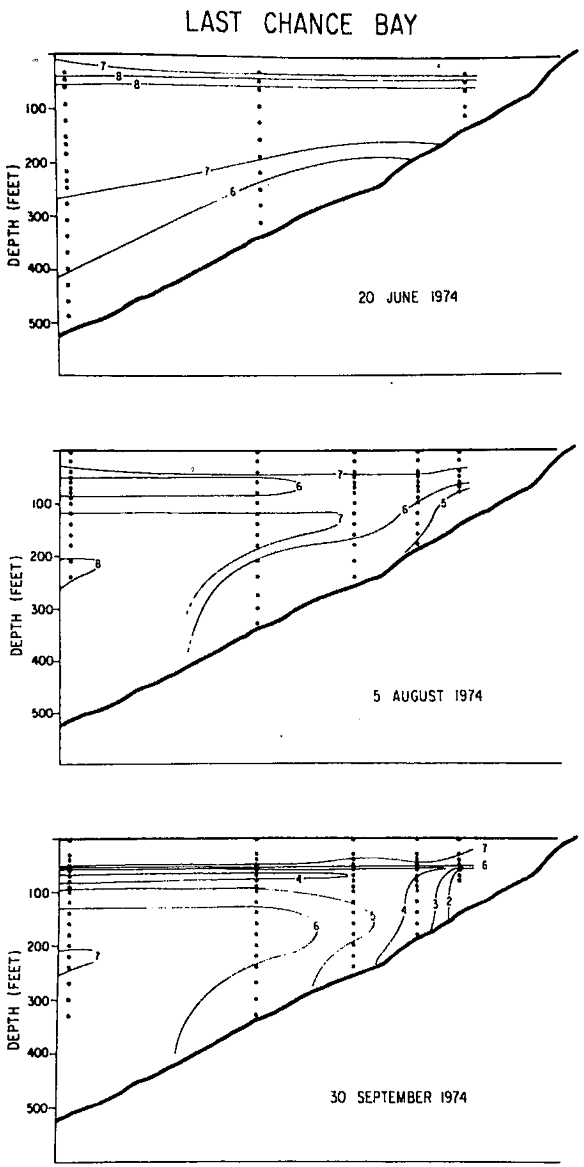

Figure 4.
Development of oxygen minimum layer in Last Chance Bay (Figure 1) during 1974.

The origin of the oxygen depletion is presumably the respiration of organic "rain" as it falls into the higher density and viscosity water of the upper metalimnion where its fall is impeded. The amount of oxygen consumption below the epilimnion, i.e. the oxygen deficit, tends to be conservative from point-to-point along the length of any side canyon. However, even though it may be quantitatively constant from point-to-point, it is not equally distributed in depth along the length of the canyon (Figures 4 and 5). The respiration process is compressed into a smaller water volume at the heads of bays than it is at the bay mouth, so that the oxygen depletion is most intense at the bay head (Figure 5). Where the zone of oxygen depletion is sufficiently thin, anerobic conditions may obtain (Figure 3). The depth profile for oxygen transforms systematically from negative heterograde (oxygen minimum layer in mid-water) at the baymouth to clinograde (oxygen deficit at bottom) at the bayhead (see Figure 5).

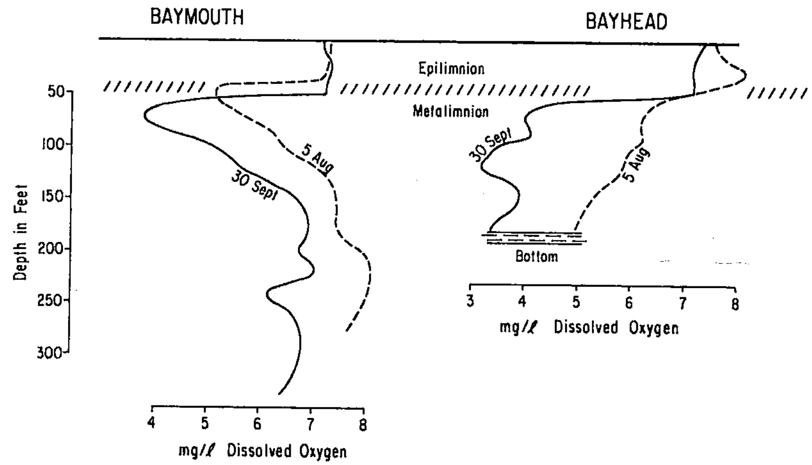

Figure 5.
A comparison of the intensity and shape of the oxygen deficit in Last Chance Bay (Figures 1 and 4) during 1974 as observed at the baymouth and the bayhead. Note that the amount of the oxygen deficit induced during the 5 August - 30 September period (the area between the two curves) is about the same. However, the oxygen deficit is distributed over a greater depth at the baymouth compared to the bayhead.

The oxygen minimum layer reaches its maximum development in September. It is systematically dissipated by convective mixing during late autumn and early winter (Johnson and Merritt, 1979). However, because convective mixing does not penetrate below the mid-depth, withdrawal current zone (Johnson and Merritt, 1979) waters below mid-depth are not resupplied with oxygen by the convective mixing process. As a result the bottom waters of Lake Powell are commonly oxygen poor (3-5 mg/l) throughout the winter. The oxygenation of the bottom water depends entirely on the advection of the winter underflow density current in Lake Powell. The underflow current gradually works its way down the lake during the winter, replacing and mixing with older, oxygen-poor water; usually reaching the dam by late March (Figure 2, column B).

An interesting situation frequently develops at the lower end of the San Juan Arm (Figure 1) where the interplay of density currents from both the San Juan River and the Colorado River sometimes traps and isolates pools of oxygen depleted water against the bottom (Figure 6).

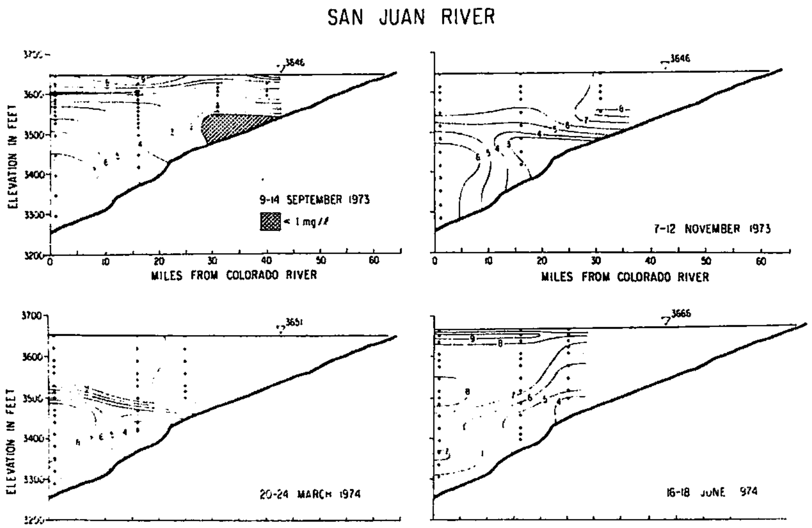

Figure 6.
Breakdown of the oxygen minimum layer (9-14 Sept.) in the San Juan Arm of Lake Powell (Figure 1) by convective mixing (7-12 Nov.) and by the intrusion of the winter underflow current from the Colorado River (20-24 Mar.) leaving a residual pocket of low-oxygen water trapped against the bottom (10-18 June).

<u>Summary</u>. The sequence of events described above reliably repeats itself on an annual basis in Lake Powell and will likely continue doing so as long as the hydrologic regimen of the lake stays in its present mode. These patterns for the distribution of oxygen have a substantial impact on the fishery of Lake Powell. Water of marginal quality for fish may be anticipated at different depths, places and times during the year. In particular the oxygen minimum layer presents a formidable barrier to the vertical migration of fish during late summer and early fall.

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